ABSTRACT

PINNIX, GARLAND DREWRY. Comparison of Green Turf Colorants on Bermudagrass and Comparison of Different Mowing and Athletic Paint Application Techniques. (Under the direction of Dr. Grady Miller).

Turf colorants are gaining popularity among turf managers in the southeastern United States due to the increase in warm-season putting greens and challenges associated with spring green-up of overseeded grasses. Previous studies confirm that green turf colorants can be an acceptable alternative to winter overseeding, however, little is known about the newer products. This study evaluates new turf colorants for duration of performance and other characteristics related to their use.

Each colorant was applied to a putting green and fairway height of dormant bermudagrass. Products were diluted based on label instructions and spray-applied at 75 mL m^{-2} and 112 mL m^{-2}. Applications were made in November 2011 and repeated in November 2012. Multidimensional Scaling and Cluster Analysis were used to group colorants into 3 groups based on visual colorant quality and coverage, and hue angle. According to visual quality data, Group 2 colorants provided the darkest green color for the longest period. A drag test procedure was developed to determine color fastness following application. Several products, including Blue, Regreen, SprayMax, World Class, Titan, Solarogen, and Endurant were found to readily transfer pigment onto a white cloth, such as might also occur with clothing or shoes. Colorant transfer was temperature dependent with less transfer at higher compared to lower temperatures (above 10°C vs. below 4°C). A subsequent study demonstrated that a second colorant application is needed three to five weeks after initial application to maintain season-long green color. Several products that rapidly faded to blue needed the earlier second application after three weeks.

Turf paint is routinely applied to athletic fields to mark boundaries and lines. Repeat applications of paint will often damage the turf, necessitating costly corrective measures. The objective of this study was to evaluate athletic paint quality and turfgrass recovery as a function of application timing and mowing frequency during the week leading up to game day.

A combination of paint applications and mowing treatments was applied to bermudagrass and perennial ryegrass turf. Both athletic paint quality and turfgrass recovery were dependent on turf species ($P \leq 0.0001$). Paint quality on bermudagrass was, on average, slightly lower than on perennial ryegrass, Mowing three times per week resulted in better turfgrass recovery compared to mowing four times per week.

Product Evaluation of Green Turf Colorants Applied to Dormant Bermudagrass and Comparison of Mowing and Athletic Paint Application Techniques

by
Garland Drewry Pinnix

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Crop Science

Raleigh, North Carolina

2014

APPROVED BY:

Dr. Grady Miller
Chair of Advisory Committee

Dr. Garry Grabow

Dr. Daniel Bowman

DEDICATION

I would like to dedicate this to my parents, Eddie and Paige Pinnix, whose encouragement and continual support have been invaluable throughout my life. It has been their desire for my success that has pushed me to reach my goals, and for that I am truly thankful. This thesis is also in memory of my grandparents, Mr. and Mrs. Garland "Mutt" Barnes and Mr. and Mrs. Edward H. Pinnix, who provided unconditional love and life-long values that will continue to guide me. Lastly, this thesis is dedicated to all of my loved ones and friends who have supported me over the years. I am grateful for all.

BIOGRAPHY

Garland Drewry Pinnix was born on March 17, 1989 to Eddie and Paige Pinnix in Franklin, Virginia. He was raised in Severn, North Carolina where he was able to spend time on the family farm, as well as the golf course in which his father was employed. Growing up in a rural environment, Drew quickly gained a passion for hunting and fishing, as well as a love for sports and when not in school, he could be found in the woods, on the river, or participating in whatever sport was in season at the time. Drew earned his high school diploma in May of 2007, from Northeast Academy in Lasker, North Carolina.

In August of 2007, Drew attended North Carolina State University to study Turf Management. During his undergraduate career, he was awarded a number of local and university scholarships and participated in two summer internships at Kilmarlic Golf Club in Powell's Point, NC and Desert Mountain Golf Properties in Scottsdale, AZ. In May of 2011, Drew completed the Bachelors of Science degree in Turf Management, with a minor in Agricultural Business Management with Honors.

In July of 2011, Drew began to work towards a Master of Science degree in Turf Management under the direction of Dr. Grady Miller. During his pursuit of his Master degree, Drew was afforded the opportunity to speak at university field days and interact with some of the most highly respected turfgrass scientists. Upon completion of his Master degree, Drew plans to continue his education by pursing a Doctor of Philosophy Degree in Turf Management at North Carolina State University.

ACKNOWLEDGMENTS

First of all, I would like to thank Dr. Grady Miller for his dedication and willingness to educate me during both my graduate and undergraduate career. Not only has Dr. Miller challenged me as a student, but has spent countless hours over the past six years guiding me through my projects and sacrificed much of his time to make sense of the many questions that I have posed. All of which, I have greatly benefited. I will forever be grateful for the opportunity that you have given me to work under your tutelage.

I would also like to thank Drs. Garry Grabow and Daniel Bowman for their guidance and willingness to offer advice during this project. Also, I would like to thank Dr. Consuelo Arellano for her help in the statistical analyses of this work.

I would also like to thank Scott Brinton, who sacrificed many hours to help carryout these experiments. It was your knowledge and assistance that made implementing these studies much smoother. I would also like to thank fellow graduate students Matt Jeffries and Casey Reynolds for their advice over the past couple of years.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 2 Comparison of Mowing and Athletic Paint Application Techniques

LIST OF FIGURES

LITERATURE REVIEW

Bermudagrass

Bermudagrass (*Cynodon* spp. Rich) is a commonly used warm-season grass for golf courses and athletic fields in the southeastern and transition zones of the United States. The transition zone is defined as the region of the United States where both warm-season and cool-season grasses are adapted to survive (Dunn and Diesburg, 2004). Bermudagrass (*Cynodon* sp.) originates from an area around the Indian Ocean, ranging from Eastern Africa to the East Indies (Beard, 1973). Throughout tropical and sub-tropical climates, bermudagrass is found in over one hundred countries worldwide and was first introduced into the United States during the colonial period (Juska and Hanson, 1964). Distribution of bermudagrass throughout the United States extends from New Jersey and Maryland, southward to Florida, and westward into Kansas and Texas. It can also be found in New Mexico, Arizona, and California under adequate irrigation (Duble, 1989).

Bermudagrass is used on lawns, cemeteries, parks, golf courses, institutional landscapes, roadsides, airfields, athletic fields, and other areas that require a general purpose turf. The popularity of bermudagrass has increased with the release of improved cultivars, which now produce a very dense, uniform, high quality turf. Bermudagrass is also capable of recovering from high traffic which makes it a favorite for golf courses and athletic field fields (Beard, 1973).

Up until the late 1940s, common bermudagrass [*Cynodon dactylon* (L). Pers.] was used on golf courses from tee to green. This species is coarse textured and produces an uneven putting surface (McCarty and Miller, 2002). In 1947, the USGA along with the USDA, introduced the finer textured and more cold hardy 'U-3' cultivar that became the desired bermudagrass (Dunn and Diesburg, 2004). In the late 1950s and 60s, the hybrid, dwarf bermudagrasses [*Cynodon dactylon* (L). Pers. × *C. transvaalensis* (Burtt-Davy)] Tifgreen' and 'Tifdwarf' were released. These grasses produced a higher shoot density, finer leaf texture, and lower growth habit compared to common bermudagrass (McCarty and Miller, 2002). These two improved cultivars gave golf course superintendents better options for bermudagrass putting greens in the southeastern United States. Even with the release of the 'Tif' bermudagrasses, up until the last decade, bentgrass putting greens have been the standard for golf courses across the United States. Ultradwarf bermudagrasses [*Cynodon dactylon* (L). Pers. × *C. transvaalensis* (Burrt-Davy)] have become increasingly popular in the southeastern United States in recent years. An increase in extreme summers in the southeast and northward into the transition zone has led many golf courses to replant their creeping bentgrass putting greens with bermudagrass. The improved ultradwarf cultivars 'TifEagle', 'Miniverde', and 'Champion' are better adapted to the climate of the upper part of the South and lower part of the transition zone than the bentgrasses (White, 2011). Fewer pesticide applications and lower labor costs are also reasons bermudagrass putting greens have become an attractive alternative to bentgrass putting greens (O'Brien and Hartwiger, 2011).

Athletic fields are one of the most challenging areas of turf to manage due to the intense traffic that they can receive over time. The principal warm-season grass grown on athletic fields in the southern region of the United States is bermudagrass (Christians, 2011). Primary reasons for choosing bermudagrass for southern athletic fields are the ability of the grass to tolerate heat and drought, as well as having a high recuperative capacity through the spreading of rhizomes and stolons (Turgeon, 2002). The ability to grow and thrive during the summer (recuperative period) is important so the turf is able to recover prior to the heavy fall sports schedule (Bigelow, 2008).

Bermudagrass may be the best adapted turfgrass for golf courses and athletic fields in the southern United States, but there are some disadvantages. Once fall temperatures drop below 60°F (15.5°C) bermudagrass will cease growth. After an extended subsequent period of time below 50°F (10°C), dormancy will be initiated (Higgins, 1999). The interaction between moderately low temperatures and bright sunlight causes chlorophyll synthesis to decline, which results in the loss of green color in warm season grasses (Youngner, 1959). This is a problem due to the demand for high visual quality for golf courses and athletic fields. Turf managers overcome this issue by overseeding during the fall with a cool-season species (ryegrass, bentgrass, or bluegrass) to maintain a green color and wearable playing surface year round (McCarty and Miller, 2002). An alternative to winter overseeding is the application of turf colorants, which can provide green color throughout the winter (Turgeon, 2002).

Turf Colorants

The use of green turf colorants has increased dramatically in recent years in the southern part of the United States. Even though turf colorants have been in existence for decades, they have not been widely used since their inception in the late 1950's. Turf colorants were first developed in Los Angeles, CA by Larry Krieger. Krieger, owner of a small paint company, formulated a combination of dyes in a water-soluble acrylic latex base that gave Hollywood movie studios the ability to create a green lawn any time of the year (Anonymous, 1987). Colorants quickly made their way into the golf industry. Due to the lack of knowledge surrounding the practice of overseeding and inefficiency of irrigation systems at the time, green turf colorants were the only option for turf managers to provide green color during winter months (Anonymous, 1987).

Advancements in irrigation systems and cool-season grasses caused winter overseeding to become the standard for winter color. Even though overseeding warm-season grasses with a cool-season grass is the most common way of providing green color during the winter season, it does not come without challenges. Cultural practices including vertical mowing, aeration, or scalping must precede overseeding to create a suitable seed bed (Cockerham, 1979.) Once the overseeded cool-season species has been established, season long maintenance including mowing, watering, fertilizer/pesticide applications, etc. is needed in order to maintain the overseeded turf at an acceptable level of quality throughout the winter. This leads to added costs during the winter months (Liu et al., 2007). For example, high seed prices during certain years can make overseeding an expensive proposition (Van Dam, 1973). Another issue is the spring transition period for warm-season grasses, which can be particularly challenging in prolonged cool, wet springs (Miller, 2011). Furthermore, competition between the two grass species can result in increased susceptibility to diseases, an increase in weed pressure, and a delay in spring green-up (Liu et al., 2007).

Turf colorants can be an attractive alternative to winter overseeding due to affordability and an easier spring transition for the warm-season specie. In 2007, establishing an overseeded turf costs upwards of $2,500 per acre. Not included in this figure are the costs of watering, fertilizing, mowing, and pest control associated with maintaining an overseeded turf. By contrast, colorant applications cost $1,600-$1,800 per acre for two applications to maintain season long color (Liu et al., 2007). In 2011, the cost of a gallon of colorant ranged from $30 to $75. This equates to an average cost of $200-$500 per acre depending on colorant brand and rate (Miller, 2011).

While lower costs are important, perhaps the most important advantage with turf colorants is an easier spring transition period. Through certain parts of the United States, especially in the southwestern US, the spring transition period is a very demanding time for turf managers. Depending on the conditions for a given year, transitioning from perennial ryegrass to bermudagrass can be smooth or very disruptive. Colorants solve any late spring transition issues by removing the competition between ryegrass and bermudagrass, causing spring green-up to be earlier and much more predictable (O'Brien, 2012).

Painted turf during the winter gives turf managers a host of options when it comes to winter weed control as opposed to an overseeded turf. Winter application of turf colorants give managers the option of using herbicides that would otherwise injure the cool-season species used for overseeding (Cockerham, 1979). Annual bluegrass (*Poa annua* L.) is one of the most troublesome weeds in turf. Since it germinates and grows during the winter months, control is very difficult in an overseeded turf. The use of colorants gives managers a greater selection of herbicides, including products that are much less expensive (O'Brien, 2012).

A major disadvantage in using turf colorants is the relatively poor wear tolerance of the playing surface. Once the painted surface on dormant turf has been damaged by traffic, there is no growth to repair it until spring green-up (Miller, 2011). The majority of colorant adheres to the leaf canopy when applied and once this canopy is destroyed, only stems remain as a sparse canopy to adsorb colorant and provide color. The resulting green appearance is much less desirable than with a full canopy of intact leaves (O'Brien, 2012). Another disadvantage with winter turf colorants is the overall appearance compared to an overseeded turf. Even though turf colorants can provide acceptable green color, a painted turf may appear much duller compared to the shiny surface of an overseeded turf (Miller, 2011).

Studies evaluating turf colorants and their effect on turf color are relatively in their results. In 2001, researchers at the University of Nebraska-Lincoln evaluated turf color and spring green-up on buffalograss (*Buchloe dactyloides* (Nutt.) Engelm.) turf plots treated with LESCO Green turf colorant (Shearman et al., 2005). Turfgrass visual ratings improved for all dates and locations compared to the untreated control when colorant was applied at either 1X or 2X the label rate. Dormant buffalograss treated with colorant was similar in appearance to Kentucky bluegrass throughout the study. Treated plots began green-up approximately two weeks earlier than the untreated control and amount of green-up was consistent with the amount of colorant applied to the individual plot. No phytotoxicity was seen during spring green-up on plots receiving twice the label rate.

A study comparing two different colorants, Mtp Turfgreen and Titan Green Turf, was conducted by Long (2006) on Champion bermudagrass. Negative aspects were noted with both products during the study with Mtp Turfgreen turning blue shortly after each application and Titan Green Turf fading around six weeks after application. It was concluded that Mtp Turfgreen would not be an acceptable alternative to overseeding due to the product's tendency to fade to a bluish color soon after application. Titan Green Turf was considered as a viable option to overseeding but multiple applications would be required to avoid fading to a bluish color. Such results were comparable to those of Liu et al. (2007) who evaluated three different colorants, Titan Green Turf, Regreen, and Green Lawnger. Liu found that all three products provided acceptable green color over the winter months on Tifeagle bermudagrass even though all three products shifted from a true green color to slightly blue over time. Lower mowing heights also yielded a better paint quality. A study conducted by Brisco et al. (2010) also found certain colorants would turn to a bluish tint over time.

Briscoe et al. (2010) evaluated twelve different turf colorants on a completely dormant Miniverde bermudagrass green as well as a semi-dormant Diamond zoysiagrass (*Zoysiagrass matrella* (L.) Merr.) putting green. Colorant increased turf color 38 to 67 percent for the Miniverde bermudagrass and from 27 to 56 percent for the Diamond zoysiagrass. It was noted that colorant application to the semi-dormant zoysiagrass resulted in better color compared to the completely dormant bermudagrass. This was due to the greater background color provided by the natural green color of the turf tissue. Researchers concluded that in order to prolong the life of all turf colorants, it is necessary to make initial applications while the turf is semi-dormant rather than waiting until the turf is completely dormant.

Colorants are able to provide acceptable green turf as well as other cultural benefits. Even though research has concluded that colorants are an acceptable alternative to winter overseeding, there are a number of unanswered questions regarding their effective use. There is little information for the various commercial products on characteristics such as viscosity and rub-off potential. It also must be determined if properly timed sequential applications can reduce the bluish tint that some products exhibit over time. This research was conducted to answer these questions so turf managers will have more information when considering turf colorants.

Athletic Turf Paint

Painting athletic fields is an important part of the art and science of sports field management (Kurcab, 2008). Painting logos, advertisements, and regulation lines are a necessity for successful competition on the field. It is also important for satisfying aesthetic needs for the twenty-first century's high level sports media markets. This is achieved by using specially formulated latex, water based paints that are non-injurious to turf species and able to exhibit a level of wearability throughout a sporting event. Field turf managers, when able, will choose a latex paint rather than a flat paint due to its brightness and ability to withstand rub-off (Koske, 2009).

Although application techniques vary among field managers, most agree that in order to achieve the best paint job possible, paint must be applied to a healthy, uniform turf. For a natural grass playing surface, proper agronomics promote a safe playing field, uniform green color, and a healthy medium that will enhance the appearance of turf paint (Wightman et al., 2007). Both pre-diluted and non-diluted paints are available. Depending on the manufacturer, dilution recommendations range from a ratio of 1 part paint: 1 part water up to a 1:5 ratio. Field managers commonly use a 1:1 ratio for initial paint applications on football fields followed by a more dilute mix for touch-up applications, while baseball fields may use a ratio of 1:2 or 1:3 (Koske, 2009).

The majority of athletic turf paint application equipment being used today is composed of an on-board compressor or CO_2 tank, but the most modern technology being used at this time is airless striping equipment. Airless sprayers apply turf paint typically at pressures between 4830 and 10342 kPa (700 and 1500 psi) and are comprised of a piston or diaphragm pump that will drive the paint through a hose and out a constricted nozzle in which paint is atomized and applied to the surface. Airless paint sprayers allow managers to save time and money by making fewer paint applications due to paint life lasting 2-3 times longer. The ability to draw directly from paint containers and accurate pressure control also ensures uniform application (Anonymous, 2008).

Depending on team schedules and weather conditions, timing when paint applications are made can determine the quality of application. According to Kurcab (2008), it is best to mow prior to a paint application. This follows the practices that were employed at the University of Arizona during 1992 that led to their selection as STMA Football Field of the Year. Field managers at the University of Arizona would apply the initial coat of paint on the lines of the field after mowing on Wednesday. Thursday there was a light irrigation, mowing on Friday, and the final painting of lines and logos for a Saturday football game (Trulio, 1992).

Although athletic field paints are formulated to avoid damaging turf, field managers regularly see a decline in turf health following sequential applications of paint (Reynolds et al., 2012). Most field managers will agree that more is not always better when it comes to field painting not only due to the cost of paint, but more importantly, from an agronomic standpoint (Wightman et al., 2007). Applying paint at high pressures and lower dilution rates (more paint:water) can severely damage turfgrass (Anonymous, 2008).

Reynolds et al. (2012) conducted growth chamber experiments examining the effects of weekly applications of red and white athletic field paint on total canopy photosynthesis (TCP) of perennial ryegrass (*Lolium perenne* L.). Spectroradiometry was used to measure reflection, adsorption, and transmission of light based on paint color, dilution, and thickness. Results from the study showed that TCP was reduced based on both color and dilution of paint. Compared to the untreated control, TCP was reduced 19% with white 1:1 dilution paint up to 75% with red no-dilution treatments. Red paint absorbed 51% of photosynthetically active radiation (PAR) while reflecting 6% and transmitting 43%. White paint absorbed 0%, reflected 95%, and transmitted 5% of PAR. These results showed that degradation in light spectral quality from sequential applications of athletic turf paint could result in a reduction of turfgrass health.

Reynolds et al. (2013) also evaluated changes in PAR and photosynthesis on Tifway hybrid bermudagrass over a range of 10 paint colors. These included black, dark blue, green, light blue, maroon, orange, purple, red, yellow, and white. They determined how different paint colors affected TCP due to alterations in absorption, reflection, and transmission of PAR. Darker colors absorbed a much higher percentage of PAR compared to lighter colors. Black absorbed the most at 94.5% of PAR while white did not absorb any PAR. Furthermore, reflection of PAR also varied strongly by color with white paint reflecting the highest amount of PAR at 92.6% while black reflected the least at 4.5%. Reflection by the darker paints was much lower than that of the lighter paints. Transmission was also color dependent, but much smaller in magnitude, with values ranging from 0.1% to 18%. White paint had the smallest impact on TCP of Tifway bermudagrass among all colors with TCP maintained at ~80%. Dark blue paint had the largest impact on TCP, reducing it to ~10% of the untreated control. Results indicated that lighter color paint pigments would reflect a higher percentage of PAR. Reflected light would be available to other areas of the turf canopy not coated with paint. Light absorbance of darker paint pigments inhibit the plant’s ability to photosynthesize.

While the underlying cause of athletic paint turf injury has been addressed, field managers continue to struggle with areas of turf where athletic paint is consistently applied. There are still many questions revolving around the management of these areas that remain unanswered. This research evaluated different management practices designed to reduce the impact that athletic paint has on turfgrass health.

LITERATURE CITED

Anonymous. 2008. Field painting advice from suppliers. SportsTurf. 24(7):34, 36, 38.

Anonymous. 1987. Paints & colorants. SportsTurf. 3(12): 14-16, 18-19.

Beard, J.B. 1973. Turfgrass: Science and Culture. Prentice-Hall, Englewood Cliffs, NJ.

Bigelow, C. A. 2008. Bermudagrass traffic tolerance-latest results. SportsTurf. 24(5):8, 10, 12, 14.

Christians, N.E. 2007. Fundamentals of turfgrass anagement. 3rd ed. John Wiley & Sons, Hoboken, N.J.

Briscoe, K., G. Miller, and S. Brinton. 2010. Evaluation of green turf colorant as an alternative to overseeding on putting greens. Appl. Turfgrass Sci. March 26. p. 1-8

Shearman, R. C., L. A. Wit, S. Severmutlu, H. Budak, and R.E. Gaussoin. 2005. Colorant effects on dormant buffalograss turf performance. HortTechnology. 15(2):244-246.

Cockerham, S. T. 1979. Warm season grasses - special techniques. TurfNews. 2:10-11.

Duble, R.L. 1996. Turfgrasses: Their Management and Use in the Southern Zone. 2nd ed. Texas A&M University Press, College Station, TX.

Dunn, J.H. and Diesburg, K.L. 2004. Turf Management in the Transition Zone. John Wiley & Sons, Hoboken, NJ.

Higgins, J. 1999. Give bermudagrass sports turf proper fall management. Grounds Maintenance, 34(8):17.

Juska, F.V., A. A. Hanson. 1964. Evaluation of Bermudagrass Varieties for General Purpose Turf. USDA Handbook 270. Washington D.C.

Koske, Thomas J. 2009. Painting athletic turf [Online]. LSUAgCenter, Baton Rouge, LA. Available at http://www.lsuagcenter.com/en/lawn garden/commercial horticulture/turfgrass/athletic fields/Painting+Athletic+Turf.htm (verified 09 March 2013).

Kurcab, R. 2008. Field painting 101: Do's and don'ts to improve your technique. SportsField Manage. 3(4):7-10.

Liu, H., B.L. McCarty, C.M. Baldwin, W.G. Sarvis, and S.H. Long. 2007a. Painting dormant bermudagrass putting greens. Golf Course Manage. 75:86-91.

Long, S.H. 2006. Thatch control, winter painting, and plant regulator management on golf course putting greens [Online]. M.S. thesis. Clemson University, Clemson, SC. Available at http://etd.lib.clemson.edu/documents/1175184782/umi-clemson-1076.pdf (verified 26 March 2013).

McCarty, L.B. and Miller, G.L. 2002. Managing Bermudagrass Turf: Selection, Construction, Cultural Practices and Pest Management Strategies. Sleeping Bear Press, Chelsea, MI.

McCullough, P., H. Liu, L.B. McCarty. 2005. Preparing for Winter. Grounds Maintenance, 40(8):64-68.

Miller, G. 2011. Turning fields green using turf colorants. SportsTurf. 27(12):16, 18-19.

O'Brien, P. 2012. Instant overseeding: Coming to a fairway near you: Turf colorants are a capable replacement for winter ryegrass overseeding. USGA Green Sec. Rec. 50(14):1-6.

O'Brien, P., and C. Hartwiger. 2011. A time to change: The ultradwarf bermudagrass putting green golf model is solid in the southern USA. USGA Green Sec. Rec. 49(8):1-5.

Reynolds, W. C., G. L. Miller, and T. W. Rufty. 2013. Athletic field paint color differentially alters light spectral quality and bermudagrass photosynthesis. Crop Sci. 53(5): 2209-2217.

Reynolds, W. C., G. L. Miller, and T. W. Rufty. 2012. Athletic field paint impacts light spectral quality and turfgrass photosynthesis. Crop Sci. 52(5):2375-2384.

Trulio, M. 1994. Picture perfect field painting and striping. SportsTurf. 10(6):30-33.

Turgeon, A.J. 2008. Turfgrass Management. 8th ed. Prentice-Hall, Inc., Upper Saddle River, N.J.

Van Dam, J. 1973. Colorants may be one answer to higher seed prices. USGA Green Sec. Rec. 11(4):6-8.

White, B. 2011. Moving north with ultradwarf bermudagrass greens. Bulletin for Sports Surface Manage. 255:35-37.

Whitlark, B., and K. Umeda. 2012. A new hue: A guide to using colorants to enhance the color and growth of fine turfgrass in the southwestern U.S.. USGA Green Sec. Rec. 50(20):1-6.

Wightman, S., B. Campbell, and T. Leonard. 2007. Top 5 painting recommendations, Part 1. SportsTurf. 23(7):28-34

Youngner, Victor B. 1959. Southern California Turfgrass Culture. 9(4):25-26.

CHAPTER 1

Product Evaluation of Green Turf Colorants Applied to Dormant Bermudagrass

A field experiment was used to evaluate the effects of 27 turfgrass colorants applied to dormant bermudagrass. A single application of each colorant was applied at two rates (75 mL m^{-2} and 112 mL m^{-2}), on two heights of cut, and diluted based on individual labeled instructions. Colorants were evaluated based on visual longevity and quality, as well as hue values produced from digital image analysis (DIA). Multidimensional scaling and cluster analysis was used to separate colorants into three groups. Group 1 colorants maintained color the longest, but colorant quality was reduced due to bright blue (Munsell color chip 5BG/6/6) and lime green colors (Munsell color chip 7.5GY/7/10). Group 2 colorants provided the darkest green (Munsell color chip 5GY/4/4) color for the longest period. Group 3 colorants provided minimal color to dormant turf after initial application. Additional field experiments were initiated to monitor colorant disassociation from turfgrass and proper timing for a sequential application. Colorant transfer testing showed that Blue, Regreen, SprayMax, World Class, Titan, Solarogen, and Endurant have the highest tendency to disassociate from the turf foliage. Colorant transfer is dependent on temperature during application, with transfer being at least 38% lower when applied at temperatures above 10°C compared to temperatures below 4°C. Due to color fading, a second application would be needed between the third and fifth week after initial application. Colorants that faded to a bluish color needed a second application three weeks after while colorants that maintained a dark green color could last five weeks. Digital Image Analysis failed to account for negative traits of some colorants. Colorant ranking was based upon visual data up until a second application was needed at 5 weeks. Group 2 colorants performed the best within the first five weeks after application, with Southwest Green (SWG), Green Lawnger, Ultradwarf Super (UDS), Experimental 2, Endurant, and Lesco Green performing the best during both years of the study. Although Endurant was among the top performing products visually, its susceptibility to colorant transfer should also be considered.

Introduction

During the last decade, improved bermudagrass cultivars have become increasingly popular in the southeastern United States for golf course putting greens. This can be attributed to the transition zone being one of the most difficult areas in the United States to grow turfgrasses. Cold winters create issues for warm-season grasses while hot, humid summers increase stress on cool-season grasses. Extreme summer heat that is common in the southeast has recently moved further north into the transition zone. The improved ultradwarf cultivars ‘TifEagle’, ‘Miniverde’, and ‘Champion’ are better adapted to the climate of the upper part of the South and lower part of the transition zone than the bentgrasses (White, 2011). The common practice for turf managers has been to overseed dormant bermudagrass during winter months (Long, 2006). As a result, the spring transition period for warm-season grasses can be challenging due to prolonged cool, wet springs (Miller, 2011). The application of turf colorants has recently increased in popularity among turf managers in the southeast. Turf colorants can be an attractive alternative to winter overseeding due to affordability and easier spring transition for warm-season grasses (Liu et al., 2007).

The conversion from cool-season to warm-season putting greens has increased in recent years. This has left turf managers dealing with the challenges associated with growing warm-season grasses during winter months. Providing green color during the winter is a primary concern. Even though overseeding warm-season grasses with a cool-season grass is the most common way of providing green color during the winter season, it does not come without challenges. Cultural practices including vertical mowing, aeration, or scalping must precede overseeding to create a suitable seed bed (Cockerham, 1979). Also, season long maintenance of cool-season grasses including mowing, watering, fertilizer, and pesticides can be costly (Liu et al., 2007).

Cost analysis is a major factor when comparing overseeding and turf colorants. In 2007, establishing an overseeded turf cost upwards of $2,500 per acre. Colorant applications ranged from $1,600-$1,800 per acre for two applications (Liu et al., 2007). In 2011, the cost of a gallon of turf colorant could range from $30-$75, resulting in an average cost between $200 and $500 per acre (Miller, 2011).

While lower costs are important, perhaps the most important advantage with turf colorants is an easier spring transition period. Colorants solve any late spring transition issues due to the lack of competition between ryegrass and bermudagrass, causing spring green-up to be earlier and much more predictable (O'Brien, 2012). Winter application of turf colorants give managers the option of using herbicides that would otherwise injure the cool-season species used for overseeding (Cockerham, 1979). This is important for the control of troublesome weeds such as annual bluegrass because of the greater assortment of herbicides to choose from, including herbicides that are much cheaper (O'Brien, 2012).

There are problems that are associated with turf colorants. A major disadvantage in using turf colorants is the relatively poor wear tolerance of the playing surface. Once traffic has compromised the painted surface, there will be no regeneration of plant tissue until spring green-up (Miller, 2011). When exposed to increased traffic, only stems remain as a sparse canopy to adsorb colorant and provide color (O'Brien, 2012). There is also a realization that must be made when comparing turf colorants to an overseeded turf. Turf colorants are capable of providing acceptable green color, but cannot provide the bright, shiny surface of a striped overseeded turf (Miller, 2011).

Turf colorants have been used since the late 1950's after being introduced by Larry Krieger to Hollywood movie sets (Anonymous, 1987). Over a half of a century later, there are still a number of questions that surround these products. With an increase in the establishment of ultradwarf bermudagrass putting greens and a proliferation in turf colorants now available to the turf industry, the objective of this research was to evaluate twenty-seven colorant products. Secondary objectives were to gain a better understanding on how these products perform in regard to colorant disassociation from the leaf and proper timing for a second application in order to maximize colorant performance.

Materials and Methods

2011-2013 Product Evaluation Study

A field experiment was conducted from the fall 2011 to spring 2012 and repeated the following fall 2012 to spring 2013 at the North Carolina State University Lake Wheeler Turfgrass Field Laboratory, in Raleigh, North Carolina. Twenty-seven turfgrass colorants were evaluated for color longevity. The study was conducted on 'Miniverde' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] maintained as a putting green. Colorants were also applied to 'Patriot' (year 1) and 'Celebration' (year 2) bermudagrass maintained to athletic field standards. Colorant application was alternated from Patriot to

Celebration bermudagrass between years due to use conflicts. Twenty seven different colorants were applied to 0.9 m x 1.8 m plots of Miniverde at two rates. A total of fifty five treatments (27 products at 2 rates with an untreated control) were arranged in a randomized complete block design, with four replications. Colorants applied on the Patriot and Celebration turfgrasses were arranged in a randomized complete block design with 51 treatments (25 products at 2 rates with an untreated control), on 0.9 m x 1.8 m plots with four replications. The two experimental products were withheld from the experiment on the taller mown turf due to space limitations.

Colorants that were included in the study are found in Table 1: Green Lawnger (Becker Underwood, Ames, IA), LESCO Green (John Deere Landscapes, Alpharetta, GA),Mtp Turfgreen (Missouri Turf Colorant, Kansas City, MO), Titan Green Turf (Burnett Athletics, Inc., Campobello, SC), Regreen (Precision Laboratories, Inc., Waukegan, IL), Wintergreen Plus (Precision Laboratories, Inc., Waukegan, IL), Ultradwarf Super (Pioneer Athletics, Cleveland, OH), Ultradwarf Plus (Pioneer Athletics, Cleveland, OH), Bermudagrass (Pioneer Athletics, Cleveland, OH), Southwest Green (Pioneer Athletics, Cleveland, OH), Experimental 1 (Pioneer Athletics, Cleveland, OH), Experimental 2 (Pioneer Athletics, Cleveland, OH), Turf Cote (NaEx Corp/Poulenger USA, Inc., Houston, TX), Endurant Turf Colorant (Geoponics Corp., Naples, FL), Green Lawnger-Graphics (Becker Underwood, Ames, IA), Green Lawnger-Lineman (Becker Underwood, Ames, IA), Super Cover (J.C. Whitlam Manufacturing, Wadsworth, OH), Evergreen (Milliken & Company, Spartanburg, SC), Green Dye Turf Colorant (World Class Athletic Surfaces, Leland, MS), Kameelyan-Bermuda (D. Ervasti Sales Co., Sauk Rapids, MN), Kameelyan-Blue (D. Ervasti Sales Co., Sauk Rapids, MN), Enviroseal Go Green (Enviroseal Corp., Port St. Lucie, FL), Sugar-Hill Turf Dye (US Specialty Coatings, Inc., Norcross, GA), Original (US Specialty Coatings, Inc., Norcross, GA), Southwestern (US Specialty Coatings, Inc., Norcross, GA), SprayMax (Harrells, Lakeland, FL), and Solarogen Green Lawn Paint (Solarogen LLC., High Point, NC). Colorant name and manufacturer were current at the initiation of these trials. As this is a dynamic and evolving industry segment, some change has occurred since this initiation.

In 2011, treatments were applied to completely dormant Miniverde and Patriot bermudagrass on 15 and 22 November 2011, respectively. In 2012, treatments were applied to completely dormant Miniverde and Celebration bermudagrass on 9 and 30 November 2012, respectively. Colorant treatments were applied in alternating directions to ensure uniform coverage, using a CO_2-pressurized boom sprayer with two TeeJet 8004 flat fan nozzles (Spraying Systems Co., Wheaton, IL) spaced 41 cm apart and calibrated to deliver 37 mL m^{-2} (40 gpa). Each colorant was applied at a low (2 passes) and high rate (3 passes). Colorant applied at the low rate corresponded to 75 mL m^{-2} (80 gpa) and the high rate to 112 mL m^{-2} (120 gpa). The rates were chosen based on manufacturers suggested rates, as well as to provide a low and high rate to compare among all turf colorants. Colorants were diluted based on label instructions. The lowest dilution (most colorant:water) from each label was chosen for the study. Across all product labels, dilutions ranged from 1:4 to 1:16 colorant:water (Table 1). Visual colorant quality ratings were taken weekly from initial colorant application until initial indication of spring green-up, using a 1 to 9 scale (1 = brown turf, 6 = acceptable color, 9 = dark green color) modified to accommodate the different colors of colorants evaluated. Initial colors among the products tested included bright blue, bright green, and dark green. The bright blue color was similar to color chip 5BG/6/6 from the Munsell Color Chart for Plant Tissues while lime green was similar to color chip 7.5GY/7/10. The darkest green color among the products tested was most similar to Munsell color chip 5GY/4/4. Products determined to have a bright blue or lime green color were both initially rated a 7, while dark green was initially rated a 9. Visual colorant coverage ratings were measured on a scale of 0-100 % (0 = no colorant, 100 = entire area coated with colorant) were taken at the same time as visual colorant quality ratings. Visual evaluations were made from approximately six feet above the turfgrass surface.

Digital photographs of plots were taken in jpeg (joint photographic experts group, ".jpg") format every two weeks during the study. Photographs were taken using a Nikon D80 digital camera (Nikon Inc., Melville, N.Y.) housed in light box that provided a uniform light source to avoid any alterations in light due to cloud cover or shadowing (Ikemura, 2003). During year one of the product evaluation study, camera settings were manually adjusted to ensure consistent capture conditions for all images. Camera settings included an aperture setting of f/5.6, a shutter speed of 1/50 second, and a focal length of 18 mm. Images were collected at an image size of "small" which is equal to a pixel count of 1,936 × 1,296. Manual settings during year two were adjusted to an aperture setting of f/13, a shutter speed of 1/13 second, and a focal length of 30 mm. The resolution of photographs captured during year two was changed to an image size of “medium” with a pixel count of 2,896 × 1,944. Images were first analyzed for red, green, and blue (RGB) values for all pixels in the acquired photographs. RGB values were then converted into hue, saturation, and brightness values. Hue angle calculation is dependent on which value among RGB levels is maximum, deeming one of three algorithms appropriate to transform RGB values into a single hue value (Adobe Systems, 2002).

Photographs were transferred to a computer and resized to a pixel count of 640 × 430 to reduce the amount of hard drive space. RGB levels for each pixel along with pixel location were determined by a macro developed with ImageJ software (National Institutes of Health, Bethesda, Md.) and exported to a text file. Text files were analyzed by code written in R language version 2.14.1 (R Development Core Team, 2011) to convert RGB levels to percentages by dividing each value by 255, convert RGB percentages into hue, saturation, and brightness (HSB) levels for each pixel, and use HSB to calculate a dark green color index (DGCI) for each pixel (Ghali et al., 2012). Basic statistics and tables for RGB levels, HSB levels, and DGCI values were also computed using R code.

2012-2013 Colorant Drag Test Study

A field experiment examining colorant transfer from treated turfgrass onto white towels was conducted during the winter months of 2012 and 2013 at the North Carolina State University Lake Wheeler Field Laboratory located in Raleigh, North Carolina. Treatments were conducted on ‘Tifway’ maintained at 2.5 cm.

Drag test data were collected using a device developed by researchers at North Carolina State University. This device (Fig. 1) consisted of two boards stacked on one another, with a 4.5 kg weight mounted on top. The bottom board dimensions were 25 × 9 × 2 cm while the top board dimensions were 23 × 9 × 2 cm allowing for a 2 cm recess at the front of the board allowing room for an eye-hook connected to a string used to pull the apparatus across plots. Scott Rags in a Box (Kimberly-Clark Corporation, Neenah, WI) with a dimension of 33 cm × 25 cm were used to collect any colorant that transferred off treated turf plots. The rag was wrapped around the bottom board and held in place by four bolts, which were secured by inserting bolts into recessed holes in the top board. Prior to dragging, the plot was sprayed with water at a rate of 75 mL m^{-2}. The drag apparatus was then dragged the length of the plot and the rags were taken back to the laboratory for further analysis. Drag tests were conducted on plots that received the higher application rate.

Products chosen to be in the drag test study were in the upper quartile of visual colorant transfer, and included Titan Green Turf, Regreen, Endurant Turf Colorant, Green Dye Turf Colorant, Kameelyan-Blue, SprayMax, and Solarogen Green Lawn Paint. Ultradwarf Super turf colorant was also included to serve as a standard for acceptable amount of colorant transfer. Eight colorant treatments along with a control (no colorant) were applied to 1.8 m × 1.8 m plots at an application rate of 112 mL m^{-2}. Treatments were arranged in a randomized complete block design with three replications. A single treatment application was applied to completely dormant bermudagrass on 6 February 2012 and 5 February 2013.

Spectral reflectance measurements were conducted on drag test rags with a FieldScout TCM 500 NDVI Turf Color Meter (Spectrum Technologies, Plainfield, IL) to calculate normalized difference vegetation index (NDVI). In order to reduce variation, NDVI measurements were taken with the rag resting on a black laboratory counter. A single reflectance measurement, which covered 45 cm^2 was taken in the center of the 215 cm^2 area of colorant transfer to document colorant rub-off.

A subsequent study was initiated in 2013 to examine colorant dependence on temperature for transfer onto a white surface. SprayMax and Ultradwarf Super were the two colorants evaluated during the two application temperatures. Colorant transfer was assessed over two 3-day periods after colorants were applied during a day of cold weather (below 4°C) and a day of warm weather (above 16°C).

The colorant treatments were applied using a CO_2-pressurized boom sprayer with four TeeJet 11004 (Spraying Systems Co., Wheaton, IL) flat fan nozzles calibrated at 56 mL m^{-2}. The products were mixed with the most colorant:water ratio recommended. Lastly, in order to achieve an application rate of 112 mL m^{-2} and ensuring uniform coverage, colorants were sprayed in two directions.

2011-2013 Sequential Application Study

A field experiment was conducted on ‘Zeon’ zoysiagrass from the winter 2011 to spring 2012 and replicated the following year during the winter 2012 to spring 2013 at the North Carolina State University Lake Wheeler Turfgrass Field Laboratory, in Raleigh, North

Carolina. The goal was to determine if a second application of colorant would provide acceptable season-long visual quality.

The two colorants chosen for this study were Green Lawnger and Evergreen. Green Lawnger is a product that was determined to have a lasting natural color while Evergreen faded to a bluish tint over time. The objective of this study was to examine if a properly timed second application of colorant could help prevent a product from fading to a bluish color over time. Colorant treated plots were 0.9 m × 0.9 m in a randomized complete block design with three replications. There were fifteen treatments (2 products, 7 treatments: single application without a second application, second application at 3 weeks, 4 weeks, 5 weeks, 6 weeks, 7 weeks, or 8 weeks, and an untreated control). Colorant treatments were initially applied to completely dormant zoysiagrass on 20 December 2011 during year one and on 10 January 2013 during year two.

Colorant treatments were applied using a CO_2-pressurized boom sprayer with a single TeeJet 8003EVS (Spraying Systems Co., Wheaton, IL) flat fan nozzle calibrated at 37 mL m^{-2}. Green Lawnger and Evergreen were mixed at a ratio of 1:7 and 1:10, respectively. Colorant was applied in three passes in order to achieve complete coverage as well the target rate of 112 mL m^{-2}.

Visual colorant quality and coverage ratings were taken each week from initial application until the last week of colorant application.

Viscosity Measurements

A #1 or #2 S90 Zahn Signature Series Dip Cup (Paul N. Gardner Company, Inc., Pompano Beach, FL) was used to measure product viscosity. The #1 cup was chosen for less viscous colorants while the #2 cup was chosen for highly viscous products. Non-diluted colorants were equilibrated between 25° and 26°C prior to viscosity measurement. Viscosity measurements were taken by recording the time it took each colorant to drain through the given cup. The resulting time was used to calculate the viscosity in centistokes (1 centistoke [cSt] = 1 millimeter^2/second [mm^2/s]) using the following equations:

#1 S90 Zahn: $V = 1.59T - 1070/T$

#2 S90 Zahn: $V = 4.18T - 760/T$

Each colorant viscosity test was replicated three times. The viscosity of several products was outside the recommended range of our measuring instruments. To overcome this issue, linear regression was used for ten products to predict non-diluted viscosities by measuring the viscosity of colorants with increasing amounts of water.

Creating a Colorant Scoring Algorithm

Attempts were made to create a colorant scoring system by using data obtained through digital image analysis. Hue, saturation, brightness, dark green color index; standard deviations for hue, saturation, and brightness; skewness of hue, saturation, and brightness; kurtosis of hue, saturation, and brightness were all used in an attempt to formulate an algorithm to rank colorants based on color. The digital imaging measures listed above were subjected to different algorithms as well as statistical procedures in order to detail if an algorithm could produce a score that would correlate to colorant visual quality data.

Colorants were applied to a 2-dimesional surface (cream colored manila sheet) at the same high rate (112 mL m^{-2}) as applied to a 3-dimenisonal surface (turf). Colorant paper samples were photographed and digitally analyzed to compare DGCI (Dark Green Color Index) and hue values to corresponding values for treated plots on the Miniverde bermudagrass after initial application. This comparison evaluated how a product's color changed after being applied to dormant turfgrass.

All statistical analyses were performed using Statistical Analysis System (version 9.3, 2012; SAS Institute Inc., Cary, NC). Distance matrices were first created to compute various measures of distance, similarity, or dissimilarity between colorant products using PROC DISTANCE. Distance matrices were used as input datasets for multidimensional scaling analysis to determine similarities between colorant products using PROC MDS. Resulting PROC MDS coordinates were subjected to cluster analysis in order to produce groups of colorants that perform similarly to be independently analyzed using PROC FASTCLUS. Colorant coverage, quality, hue angle, and NDVI data were subjected to analysis of variance to determine treatment effects and subsequent interactions using the PROC GLM procedure. Mean separation procedures were subjected to Fisher's Protected LSD test at the 0.05 probability level. PROC STEPWISE was used to seek coefficients for digital imaging data that would produce an algorithm used to score colorants over time.

Discriminant analysis was performed to further examine the relationship between turf colorants. Discriminant analysis uses PROC DISCRIM to determine which colorant products, among groups, were most similar to one another based on colorant coverage, quality, and hue information through a quadratic discriminant rule.

Results and Discussion

2011-2013 Product Evaluation Study

In both years of the study, certain colorants performed similarly when evaluating colorant quality, colorant coverage, and hue (Fig 2). Data were subjected to Multidimensional Scaling (MDS) analysis, with resulting MDS coordinates clustered into three groups based on visual colorant coverage, colorant quality ratings, and colorant hue angles (Fig. 3, Fig.4). Products in Group 1 characterized are bright blue and lime green in color with good colorant longevity and higher hue values; products in Group 2 are a dark, natural green color but with reduced longevity and lower hue values; products in Group 3 have minimal color, short longevity and very low hue values. Colorants were clustered using visual colorant coverage, colorant quality ratings, and colorant hue angles. Data was averaged over both application rates and years of study for both heights of cut. The results of the clustering can be found in Fig. 3 and 4, respectively.

There was no effect of mowing height on Group 1 colorants, with the exception of Green Lawnger. Green Lawnger fell into Group 2 when applied to Miniverde bermudagrass and Group 1 when applied to Patriot and Celebration. Conversely, Go Green was included in

Group 1 when applied to Miniverde and Group 2 when applied to Patriot and Celebration. Mowing height also did not affect Group 2 colorants, with the exception of Sugar Hill. Sugar Hill was categorized as Group 2 when applied to Miniverde and Group 3 when applied to Patriot and Celebration. Furthermore, Ultradwarf Plus (UDP) was a Group 3 colorant when applied to Miniverde and a Group 2 colorant when applied to Patriot and Celebration. In Figures 3 and 4, colorants on the left side of the graphs will retain color longer than the colorants towards the right.

Data analysis did not adequately account for the bright blue and lime green color of certain colorants, similar to findings by Briscoe et al. (2010). Products that were bright blue and green retained color the longest, resulting in averaged colorant quality, coverage, and hue values being rated higher. This was troublesome since this suggests that bright blue or lime green colorants, both of which may not be ideal for high valued turf, are the superior products. Having group designations alleviates this issue allowing for a better assessment for ranking turf colorants within groups.

Significant interactions occurred among all treatment effects for colorant coverage, quality, and hue for both heights of bermudagrass. The only interaction not significant was between year and rate for colorant coverage and hue (Tables 2 and 3). Group 1 colorants on Miniverde resulted in a range of 61-78% colorant coverage, colorant quality of 5-7, and hue values of 55-73° in year one followed by 59-84% coverage, quality of 5-7, and hue values of 56-80° during year two of the study (Table 4). During year one, group 2 colorants on Miniverde had a range of 40-77% coverage, 4-7 quality, and 46-54° hue and in year two ranges of 43-70% coverage, 4-7 quality, and 49-61° hue (Table 5). Group 3 colorants on Miniverde resulted in ranges of 19-53% coverage, 2-5 quality, and 43-55° hue followed by 6-33% coverage, 1-4 quality, and 47-50° hue during year one and two, respectively (Table 6).

Group 1 colorants on Patriot and Celebration had a range of 55-72% colorant coverage, 5-6 colorant quality, and 55-72° hue values followed by 59-79% coverage, 5-7 quality, and 59-77° hue ranges during year one and two, respectively (Table 7). Group 2 colorants on Patriot and Celebration had ranges of 38-60% coverage, 4-5 quality, and 49-57° hue values in year one followed by 31-58% coverage, 4-6 quality, and 52-60° hue in year two (Table 8). Lastly, group 3 colorants on Patriot and Celebration ranged from 24-42% for coverage, 2-4 quality, and 43-56° hue during year one and 3-32% coverage, 1-4 quality, and 45-51° hue during year two (Table 9).

Colorant coverage, colorant quality, and hue values were higher for each group when applied to Miniverde with exception of Group 2 hue values during year one and Group 3 hue values during both years. This can be attributed to the small amount of colorant on the leaf and the taller mown turf being less dense. The software can detect darker/shaded areas near the soil surface on the taller mown turf as opposed to the lighter color expressed by the denser Miniverde. The dark color lower in the canopy will result in higher hue values.

Quadratic discriminant analysis was used to see how colorants compared to one another. Tables 11 and 12 show which colorants are more similar or dissimilar within group. For example, Bermuda applied to Miniverde bermudagrass was wrongly classified as Blue 7.2% of the time, Dye 22.4%, Go Green 15.8%, Regreen 3.3%, and Wintergreen 43.3%

(Table 10). This indicates that Bermuda was most similar to Wintergreen and Dye and most dissimilar to Blue and Regreen within group 1.

High error rates seen in the cross-validation summary tables also illustrate the large degree of similarity of the products in each group. Error estimates range from 49% for Sugar Hill to 100% for Graphics within Miniverde group 2 colorants (Table 11). This indicates that most colorants were mistaken with other colorants during the experiment. Such high error estimates supports Figures 2 and 3 as accurate separations of products due to the inability of the quadratic discriminant analysis to differentiate between colorants. Cross-validation summary tables for remaining groups on both grasses can be found in the Appendices.

Multidimensional scaling analysis combines numerous data (colorant coverage, quality, and hue) and presents it on a 2-dimensional scale. Dimension values can be arbitrary, so it is important to note the relative positions of each product within each plot rather than dimension coordinates. When examining scatterplots, colorants that have a darker color and higher coverage percentage will be on the left side of the plot whereas loss of color and coverage will position the colorant further to the right. Graphical displays were used to monitor colorants and their relationship to other colorants throughout the study. For example, Blue, Dye, Bermuda, Regreen, Wintergreen, Go Green, Lawnger, and Titan are grouped together at 6 days after application (DAA) on Celebration bermudagrass (Figure 5). At 53 DAA, Titan has shifted towards the center of the scatterplot as it began to fade leaving Blue, Dye, Wintergreen, Regreen, Bermuda, Go Green, and Lawnger still in the group that has the most color and highest coverage. By 111 DAA, all colorants had shifted towards the right over time with the exception of Blue, Dye, and Wintergreen. Multidimensional scatterplots for each rate and height of cut can be found in the Appendices.

2012-2013 Colorant Drag Test Study

Analysis of colorant disassociation revealed that a colorant's ability to transfer from the turf foliage onto a white rag was dependent on year, colorant treatment, days after application within year, year × treatment, and treatment × days after application within year interactions (Table 12). One day after colorant application in 2012, NDVI values for colorant transfer ranged from 0.033 for UDS to 0.233 for Blue (Table 13). By two days after application, Blue and Regreen had a 0.4 and 23% increase in colorant transfer, respectively. Endurant, Solarogen, SprayMax, Titan, UDS, and Dye saw reductions of 29, 17, 21, 33, 42, and 5%, respectively by two days after application. One day after colorant application in 2013, NDVI values ranged from 0.017 for UDS to 0.113 for Blue and Regreen (Table 14). Two days after application in 2013, colorant transfer increased 30% for Blue, Solarogen 13%, and SprayMax 31%. Colorant transfer remained the same for UDS, while Endurant, Regreen, Titan, and Dye saw reductions of 11, 10, 7, and 2 %, respectively. Based on these results, we set a threshold value for an acceptable level of colorant transfer of 0.030. UDS had the least amount of colorant transfer in 2012, but was above the threshold of 0.030 after initial application due to application in sub-optimal temperatures. In 2013 UDS was below the 0.030 value throughout the duration of the study. Blue and Regreen stayed well above the acceptable level of colorant transfer during both years of the study. The time it took for the remaining products to achieve the acceptable colorant transfer level can be found in tables 13 and 14.

There was higher colorant transfer during 2012 compared to 2013 (Fig. 6), which we attributed to differences in air temperature at the time of colorant application. In 2012, the high temperature on the day of application was 9°C (48°F) compared to 16°C (61°F) in 2013. In addition, the average daily temperatures for the first couple of days after application in 2012 were much lower than in 2013 (Fig. 7). Due to the possible temperature dependence on colorant transfer, a separate study was conducted. Ultradwarf Super and SprayMax were chosen as representing colorants not prone and prone to colorant transfer, respectively. Analysis of variance confirmed that colorant transfer was dependent on air temperature during application (Table 15). When applied at acceptable temperatures (Fig. 8), Ultradwarf Super and SprayMax colorant transfer was 72 and 38% lower than when applied at sub-optimal temperatures, respectively one day after application (Fig. 9). At three days after application Ultradwarf Super transfer was much lower relative to when it was applied in cooler temperatures; whereas SprayMax was 32 % lower. These results suggest that colorants are more likely to transfer onto an absorbent material when applied at temperatures below 10°C.

In many areas that colorants are used, golf courses and sports fields especially, colorant transfer onto clothing or other items while playing the sport can be problematic and costly. Uniforms severely stained with turf colorants can be a major cost to sports teams. Furthermore, golfers paying to play do not want colorant stained shoes or clothing after playing a round of golf. It is imperative for turf managers to be cognizant of these products tested as well as applying colorant when temperatures are above 10°C. Avoiding certain products prone to transfer and applying colorant in warmer temperatures will help prevent colorant disassociation.

2011-2013 Sequential Application Study

The saturation of all turf colorants will degrade over time while some colorants will completely change color from a dark green color to a bluish or grayish color. Such changes were noticed for a couple of products, similar to reports from Briscoe et al. (2010) and Liu et al. (2007). Analysis of variance indicates that to have prolonged quality and coverage, sequential applications may be needed (Table 16). In 2012 (year one), a second application of Green Lawnger during week 4 or 5 provided the greatest colorant quality and coverage while Evergreen needed a second application during week 3 or 4 (Table 17). During 2013, a sequential application of Green Lawnger at week five provided colorant quality the longest. A second application of Evergreen at week five also provided prolonged quality in 2013. Ranges of colorant coverage for Green Lawnger were 88-98% in 2012 and 78-98% in 2013. Evergreen had ranges of 87-99% in 2012 and 78-99% in 2013. Although, colorant coverage ratings are consistent between both products, the date of the second application could not mask Evergreen's tendency to fade to a bluish color. Colorant quality ratings accurately portray this with Evergreen requiring a second application as early as 3 weeks after initial application while Green Lawnger was able to wait until 5 weeks.

Viscosity Measurements

Several practical observations were made during mixing and application of products, including how well products went into suspension and how easy it was to clean equipment. This resulted in categorizing the 27 products into four groups. Group designations were based on how easily products went into suspension and the amount of time taken to clean materials. Cleaning of materials included rinsing of beakers, funnels, and spray bottles that were all used to measure colorant. Group A colorants required an extended amount of effort to get colorants into suspension including straining of suspension to reduce solids. Group B colorants required extensive stirring of the 18.9 liter (5 gallon) stock containers prior to dilution and extended agitation. Group C colorants required agitation and mixing equipment required multiple rinses with water afterwards. Group D colorants went into suspension with minimal effort and required very little clean-up.

Group A: Kameelyan Bermuda, Kameelyan Blue

Group B: Ultradwarf Super, Ultradwarf Plus, Bermudagrass, Southwest Green, Experimental 1 and 2.

Group C: Green Lawnger, LESCO Green, Mtp Turfgreen, Regreen, Wintergreen Plus, Green Lawnger-Graphics, Green Lawnger-Lineman, Super Cover, Enviroseal Go Green, SH Turf Dye, Original, Southwestern, Solarogen

Group D: Turf Cote, Endurant, Green Dye Turf Colorant, SprayMax, Titan Green Turf, Evergreen

These observations have no bearing on how colorants performed, but pertain to the amount of effort required to prepare for application and clean up. Both Kameelyan Bermuda and Blue required using a filter while mixing which made the task more challenging compared to other products.

The importance of frequently cleaning nozzles and filters during colorant application of more viscous products was also noted. Due to some products having more solids in suspension, nozzle clogging could occur. Failure to regularly check and clean nozzles could lead to streaking and poor uniformity.

Due to differences in the amount of effort required for mixing and clean up, non-diluted viscosities were measured. Some products, even though non-diluted, were less viscous than water while other products had to be diluted to measure their viscosity. Experimental 2 colorant was the most viscous product tested at 366 centistokes, while Titan was the least viscous at -1 centistoke (Fig. 10). No explanation was found for why a couple of products were less viscous than water, other than certain surfactants are known to result in lower viscosities.

Creating a Colorant Scoring Algorithm

Digital photographs were taken throughout the Colorant Evaluation study for monitoring colorant color over time. The goals in generating these data were to (1) to accurately depict plot color, and (2) to be able to rank colorants based on hue values to correlate with visual quality ratings.

Hue angles are measured on a scale of 0-360°. Karcher and Richardson (2003) concluded that the hue range of most turfgrass images are between 60° (yellow) and 120° (green). We expected to see similar results following the application of green turf colorants, but values were much lower. Furthermore, the products that had the highest hue ratings were colorants that were either very bright blue or lime green in color. Standard hue values would suggest that blue products would have a hue value around 210°, a lime green product around 120°, and darker green product slightly lower than 120° (Fig. 11). Green Lawnger, which produced the darkest green color had an average hue value of 62° after initial application. Dye, which had a bright green color, had an average hue value of 86° and Blue an average hue value of 91°. Dormant turf (yellow) had hue values that were closer to 45°. Colorant treated dormant turf hue values were lower than expected due to the presence of un-treated dormant turf visible after colorant application (Fig. 12). After hue values across all pixels were averaged, hue values were much lower compared to the actual hue of the colorant.

An attempt to correlate hue angle with visual ratings was not successful due to bright green and blue colored products producing the highest hue angles. With their hue being bluer or bright green in color, it led to lower visual quality ratings since both colors are not a desirable color to mask turfgrass dormancy. Hue values along with other digital image generated data (saturation, brightness, dark green color index; standard deviations for hue, saturation, and brightness; skewness of hue, saturation, and brightness; kurtosis of hue, saturation, and brightness) were subjected to different algorithms in order to create a new colorant scoring system that would solely rely on digital imaging as a way to analyze products. Attempts were unsuccessful due to lack of correlation with visual quality ratings.

Further investigation into this issue led to analyzing digital photographs of colorants applied to a standardized 2-dimensional surface (manila sheet) and comparing results to data from photographs of colorants applied to a 3-dimensional surface (turf). Results indicate that all products failed to maintain true color once applied to turfgrass. This was expected, but the degree to which some products lost color was substantial. For example, Green Lawnger had a 52 and 45% decrease in DGCI and hue, respectively, when applied to turfgrass compared to the standard manila sheet. Furthermore, Green Lawnger saw an increase of 106 and 41% in DGCI and hue compared to the untreated control (Fig. 13). High standard deviations show the variability among products (Table 18). Even though a number of these products performed similarly when applied to dormant turfgrass, the degree to which they varied from a 2-dimesional surface to a 3-dimensional surface suggests that paint chemistries differ greatly. The role that surfactants, amount of pigment and binder, or any other colorant constituent play in the performance of colorants is unknown due to lack of information on product ingredients.

Conclusions

Twenty seven turf colorants, were separated into three groups. Group 1 colorants maintained color, colorant coverage, and greater hue angles the longest, but their blue and lime green colors are inappropriate for high valued turf situations. Group 2 colorants provided the darkest green color while group 3 colorants were classified as colorants having the least amount of color. As a result, Group 2 colorants performed the best visually during the study.

Since all products tend to fade over time, sequential application are required three to five weeks after initial application in order to maintain visual quality. Colorants within Group 2 that had the highest visual quality after 5 weeks were considered the top performing colorants. Top performing products in year one were SWG, Lawnger, UDS, Experimental 2, Endurant, and Lesco Green. During year two the top performing products were Lawnger, Lesco Green, UDS, SWG, Solarogen, Experimental 2, and Endurant. Visual colorant coverage ratings mirror these results with the exception of a couple of products. In 2011, Lawnger, SWG, Titan, UDS, Endurant, Evergreen, and Lesco Green provided the most colorant coverage into week 5 and in 2012, Lawnger, SprayMax, SWG, Evergreen, Titan, UDS, and Lesco Green had the highest coverage percentages. Although Titan and Evergreen were two of the top performers during both years of the study for colorant coverage, they both faded to a bluish tint three weeks after application. SprayMax will also provide good coverage, but will turn gray three weeks after initial application.

Colorant drag testing revealed that Blue, Endurant, Regreen, Solarogen, SprayMax, Titan, and World Class have the highest affinity to transfer colorant onto white cloth among all products tested. A separate study verified the importance of applying colorants at temperatures above 10°C in order to minimize rub-off potential.

There was a dramatic change in the DGCI and hue of products when applied to a 3-dimesional surface compared to a flat, 2-dimensional surface. This implies that there is a dynamic among paint formulations that allow some products to maintain color at a greater extent after being applied to dormant turfgrass.

Prior to applying a turf colorant, a turf manager should have an intended goal in mind. Whether that goal is to have a colorant last for three months or three weeks, the intended use should be known. Colorants included in this study ranged from products that persisted for an extended period to products that do not provide any color at all. Among all the products tested, Group 2 colorants will provide the darkest green color. Furthermore, colorant application must be made in temperatures above 10°C to reduce colorant transfer.

LITERATURE CITED

Adobe Systems. 2002. Adobe Photoshop v. 7.0. Adobe Systems, San Jose, CA.

Anonymous. 1987. Paints & colorants. SportsTurf. 3(12): 14-16, 18-19

Cockerham, S. T. 1979. Warm season grasses - special techniques. TurfNews. 2:10-11.

Ghali, I. E., G. L. Miller, G. L. Grabow, and R. L. Huffman. 2012. Using variability within digital images to improve tall fescue color characterization. Crop Sci. 52(5):p. 2365-2374.

Ikemura, Y. 2003. Using digital image analysis to measure the nitrogen concentration of turfgrasses. MS thesis. University of Arkansas, Fayetteville, AR.

Karcher, D.E., and M.D. Richardson. 2003. Quantifying turfgrass color using digital image analysis. Crop Sci. 43:p. 943–951.

Liu, H., B.L. McCarty, C.M. Baldwin, W.G. Sarvis, and S.H. Long. 2007. Painting dormant bermudagrass putting greens. Golf Course Manage. 75:86-91.

Long, S.H. 2006. Thatch control, winter painting, and plant regulator management on golf course putting greens [Online]. M.S. thesis. Clemson University, Clemson, SC. Available at http://etd.lib.clemson.edu/documents/1175184782/umi-clemson-1076.pdf (verified 26 March 2013).

Miller, G. 2011. Turning fields green using turf colorants. SportsTurf. 27(12):16, 18-19.

O'Brien, P. 2012. Instant overseeding: Coming to a fairway near you: Turf colorants are a capable replacement for winter ryegrass overseeding. USGA Green Sec. Rec. 50(14):1-6.

R Development Core Team. 2008. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org (accessed 13 Oct. 2011).

SAS Institute. 2013. The SAS system for Microsoft Windows, version 9.3. SAS Inst., Cary, NC.

White, B. 2011. Moving north with ultradwarf bermudagrass greens. Bulletin for Sports Surface Manage. 255:35-37.

Table 1. Treatment number, turfgrass colorant manufacturers, product names, and dilution rates used to apply colorant to a dormant bermudagrass putting green and fairway during November 2011 and 2012 at Lake Wheeler Field Laboratory in Raleigh, NC.

	Colorant Manufacturer	Colorant Name	Dilution (colorant:water)
1	Becker Underwood	Green Lawnger	1:7
2	John Deere Landscapes	Lesco Green	1:10
3	Missouri Turf Paint	Mtp Turfgreen	1:7
4	Burnett Athletics, Inc.	Titan Green Turf	1:10
5	Precision Laboratories	Regreen	1:7
6	Precision Laboratories	Wintergreen Plus	1:10
7	Pioneer Athletics	Ultradwarf Super	1:7
8	Pioneer Athletics	Ultradwarf Plus	1:7
9	Pioneer Athletics	Bermudagrass	1:7
10	Pioneer Athletics	Southwest Green	1:7
11	Pioneer Athletics	Experimental 1	1:7
12	Pioneer Athletics	Experimental 2	1:7
13	NaEx Corp/Poulenger USA, Inc.	Turf Cote	1:7
14	Geoponics Corp.	Endurant Turf Colorant	1:16
15	Becker Underwood	Green Lawnger-Graphics	1:15
16	Becker Underwood	Green Lawnger-Lineman	1:4
17	J.C. Whitlam Manufacturing	Super Cover	1:15
18	Milliken & Company	Evergreen	1:10
19	World Class Athletic Surfaces	Green Dye Turf Colorant	1:7
20	D. Ervasti Sales Co.	Kameelyan-Bermuda	1:8
21	D. Ervasti Sales Co.	Kameelyan-Blue	1:8
22	Enviroseal Corp.	Envirsoseal Go Green	1:4
23	U.S. Specialty Coatings Inc.	Sugar-Hill Turf Dye	1:15
24	U.S. Specialty Coatings Inc.	Original	1:15
25	U.S. Specialty Coatings Inc.	Southwestern	1:15
26	Harrells	SprayMax	1:16
27	Solarogen LLC.	Solarogen	1:10

Table 2. Analysis of variance for turfgrass colorant coverage, quality, and hue on Miniverde bermudagrass.

	weekly†			twice monthly‡	
		Mean Square			Mean Square
Source of Variation§	df	cover	quality	df	hue
Year, Y	1	13548.15***	29.71***	1	10580.00***
Treatment, T	26	85876.29***	523.26***	26	7126.31***
Ratings (Year), R(Y)	33	116589.36***	645.41***	17	4437.68***
Rate, R	1	441771.37***	2315.02***	1	21648.53***
Y × T	26	10071.91***	52.77***	26	278.61***
Y × R	1	14.81	14.71**	1	15.64
T × D(Y)	858	438.81***	5.97***	442	24.43***
T × R	26	1042.99***	13.84***	26	359.52***
R × D(Y)	33	1272.68***	18.10***	17	30.44***
Y × T × R	26	784.92***	6.99***	26	44.15***
T × R × D(Y)	858	128.10***	2.28***	442	5.60
Error	5670	83.88	1.58	3078	7.16
CV%		16.29	24.32		4.95
Mean		56.20	5.17		54.05

Significance at $P < 0.01$ and $P < 0.001$ levels denoted by **, ***, respectively.

† Cover and quality ratings were taken every week throughout the study.

‡ Hue was captured by digital photographs of plots taken twice monthly throughout the study.

§ Year, Y= 2011-12 and 2012-13; Treatment, T= Colorant products; Ratings D(Y)=Rating Dates (within year); R= 80 and 120 gallons per acre

Table 3. Analysis of variance for turfgrass colorant coverage, quality, and hue on Patriot and Celebration bermudagrass.

	weekly†			twice monthly‡	
		Mean Square			Mean Square
Source of Variation§	df	cover	quality	df	hue
Year, Y	1	13961.31***	34.061***	1	10852.85***
Treatment, T	24	92538.82***	558.38***	24	7629.01***
Ratings (Year), D(Y)	33	107239.69***	578.16***	17	4093.90***
Rate, R	1	400047.00***	2008.77***	1	20789.08***
Y × T	24	10883.98***	56.32***	24	284.58***
Y × R	1	74.11	16.62**	1	17.82
T × D(Y)	792	468.75***	6.28***	408	26.06***
T × R	24	1043.51***	13.61***	24	383.18***
R × D(Y)	33	1032.85***	15.23***	17	32.16***
Y × T × R	24	836.79***	7.42***	24	47.17***
T × R × D(Y)	792	131.71***	2.38***	408	5.93
Error	5250	83.57	1.65	2850	7.52
CV%		16.34	25.01		5.05
Mean		55.95	5.13		54.26

Significance at $P < 0.01$ and $P < 0.001$ levels denoted by **, ***, respectively.

† Cover and quality ratings were taken every week throughout the study.

‡ Hue was captured by digital photographs of plots taken twice monthly throughout the study.

§ Year, Y= 2011-12 and 2012-13; Treatment, T= Colorant products; Ratings D(Y)=Rating Dates (within year); R= 80 and 120 gallons per acre

Table 4. Visual turfgrass colorant cover and quality ratings, along with colorant hue angles following a single application of the Group 1 turf colorants on ‘Miniverde’ bermudagrass averaged over both rates.

	2011-12			2012-13		
Treatment	Cover†	Quality‡	Hue§	Cover	Quality	Hue
Bermuda	73.8 ab¶	6.3 a	61.9 b	67.7 cd	5.9 bc	63.2 d
Blue	78.2 a	6.7 a	73.2 a	83.5 a	6.7 a	79.9 a
Dye	74.3 ab	6.4 a	64.2 b	75.1 bc	6.3 ab	71.1 b
Go Green	60.6 c	5.4 c	55.2 d	59.3 e	5.3 d	55.9 f
Regreen	67.6 b	5.9 b	54.7 d	61.9 de	5.6 cd	59.8 e
Wintergreen	78.2 a	6.6 a	58.7 c	78.9 ab	6.6 a	66.1 c
LSD ($_{0.05}$)	6.7	0.4	3.1	8.3	0.5	2.0
CV%	28.5	21.6	15.5	37.5	29.1	9.8

† Colorant cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.
‡ Colorant quality ratings are based on the color of the colorant on a scale of 1-9.
§ Colorant hue angles were acquired from Digital Image Analysis on a scale of 0-360°.
¶ Means within columns followed by the same letter are not significantly different according to Fisher’s Protected LSD (P=0.05).

Table 5. Visual turfgrass colorant cover and quality ratings, along with colorant hue angles following a single application of the Group 2 turf colorants on 'Miniverde' bermudagrass averaged over both rates.

	2011-12			2012-13		
Treatment	Cover†	Quality‡	Hue§	Cover	Quality	Hue
Exp. 2¶	62.5 bcde#	6.0 bcd	51.0 cd	62.8 abc	5.8 cde	51.3 g
Endurant	58.8 def	5.4 def	50.0 de	51.1 de	5.1 ef	51.6 fg
Evergreen	63.9 bcde	5.6 cde	51.8 abcd	69.9 a	5.7 cde	56.7 c
Graphics	60.1 cdef	5.3 def	53.9 a	60.9 abcd	5.8 cde	57.2 c
Lawnger	76.9 a	7.3 a	50.1 de	69.6 ab	6.8 a	54.2 e
Lesco	69.2 ab	6.5 b	50.4 cde	67.4 ab	6.6 ab	52.8 f
Lineman	56.2 ef	4.8 f	50.9 cd	53.3 d	4.6 fg	51.2 g
Original	55.3 ef	4.9 f	53.8 a	66.2 ab	6.0 bcd	60.8 a
Exp. 1	56.4 ef	5.3 ef	50.7 cde	54.8 cd	5.8 cde	52.6 f
Sugar Hill	40.2 g	3.7 g	46.0 f	43.1 e	4.4 g	49.3 h
SWG	59.7 cdef	5.7 cde	48.8 e	60.4 bcd	5.6 cde	51.1 g
Solargen	51.7 f	4.8 f	53.2 ab	64.8 ab	6.3 abc	59.0 b
SprayMax	42.2 g	3.8 g	46.5 f	68.1 ab	5.5 de	51.0 g
Titan	67.8 bc	6.2 bc	52.3 abc	68.8 ab	6.1 abcd	55.9 cd
UDS	65.5 bcd	6.0 bcd	51.5 bcd	63.6 abc	6.1 abcd	54.9 de
LSD ($_{0.05}$)	8.6	0.7	2.1	9.3	0.8	1.3
CV%	44.7	40.7	12.8	48.4	42.7	7.8

† Cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.
‡ Quality ratings are based on the color of the colorant on a scale of 1-9.
§ Hue angles were acquired from Digital Image Analysis on a scale of 0-360°.
¶ Product Abbreviations: Exp. 2, Experimental 2; Exp. 1, Experimental 1; SWG, Southwest Green; UDS, Ultradwarf Super.
# Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P=0.05).

Table 6. Visual turfgrass colorant cover and quality ratings, along with colorant hue angles following a single application of the Group 3 turf colorants on ‘Miniverde’ bermudagrass averaged over both rates.

	2011-12			2012-13		
Treatment	Cover†	Quality‡	Hue§	Cover	Quality	Hue
Bermudagrass	53.3 a#	4.7 a	55.0 a	11.6 cd	1.7 cd	49.6 a
Turf Cote	24.0 d	2.4 d	43.7 d	5.6 d	1.3 d	47.1 b
Super Cover	34.3 c	3.2 c	46.9 c	21.1 b	2.7 b	49.9 a
Mtp Turfgreen	43.6 b	4.0 b	46.9 c	32.7 a	3.6 a	50.1 a
Southwestern	18.8 d	2.2 d	43.1 d	15.9 bc	2.4 bc	48.1 b
UDP¶	49.7 ab	4.6 ab	49.6 b	35.8 a	3.8 a	50.0 a
LSD ($_{0.05}$)	9.1	0.7	1.8	8.0	0.7	1.2
CV%	74.5	62.5	11.1	125.7	89.0	8.1

† Cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.
‡ Quality ratings are based on the color of the colorant on a scale of 1-9.
§ Hue angles were acquired from Digital Image Analysis on a scale of 0-360°.
¶ Product Abbreviation: UDP, Ultradwarf Plus
# Means within columns followed by the same letter are not significantly different according to Fisher’s Protected LSD (P=0.05).

Table 7. Visual turfgrass colorant cover and quality ratings, along with colorant hue angles following a single application of the Group 1 turf colorants on 'Patriot' and 'Celebration' bermudagrass averaged over both rates.

	2011-12			2012-13		
Treatment	Cover†	Quality‡	Hue§	Cover	Quality	Hue
Bermuda	55.2 c¶	4.7 b	62.4 bc	59.6 c	5.4 b	64.6 c
Blue	65.1 ab	5.7 a	72.3 a	79.4 a	6.5 a	77.4 a
Dye	71.6 a	6.1 a	69.6 a	76.6 a	6.4 a	73.4 b
Lawnger	67.0 a	6.1 a	54.6 d	70.8 ab	6.7 a	58.9 d
Regreen	56.2 bc	4.7 b	58.6 cd	65.7 bc	5.7 b	64.2 c
Wintergreen	64.9 abc	5.6 a	63.3 b	74.8 a	6.3 a	66.1 c
LSD ($_{0.05}$)	9.7	0.7	4.6	8.7	0.6	2.8
CV%	44.2	38.0	20.9	35.2	27.0	11.8

† Cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.
‡ Quality ratings are based on the color of the colorant on a scale of 1-9.
§ Hue angles were acquired from Digital Image Analysis on a scale of 0-360°.
¶ Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P=0.05).

Table 8. Visual turfgrass colorant cover and quality ratings, along with colorant hue angles following a single application of the Group 2 turf colorants on 'Patriot' and 'Celebration' bermudagrass averaged over both rates.

	2011-12			2012-13		
Treatment	Cover†	Quality‡	Hue§	Cover	Quality	Hue
Endurant	48.7 bcd#	4.6 abcd	50.3 fgh	37.9 bc	3.9 d	53.5 efg
Go Green	55.2 abc	4.8 abc	55.6 ab	58.2 a	5.3 ab	57.9 b
Evergreen	50.1 abc	4.3 bcd	52.4 cdef	49.2 ab	4.5 bcd	53.5 efg
Graphics	46.5 bcd	4.0 bcd	55.8 ab	34.3 c	3.7 d	57.9 b
Lesco	60.3 a	5.4 a	53.8 bcde	57.8 a	5.8 a	54.5 de
Lineman	44.1 cd	3.8 d	51.3 efg	46.8 ab	4.5 bcd	53.7 ef
Original	50.5 abc	4.5 abcd	55.5 abc	48.2 ab	5.0 abc	58.6 ab
SWG¶	49.7 abcd	4.8 abc	49.0 gh	39.0 bc	4.0 d	52.3 fgh
Solargen	52.3 abc	4.8 abc	57.1 a	48.1 ab	4.9 abc	59.9 a
SprayMax	44.9 bcd	3.9 cd	47.6 h	48.4 ab	4.3 cd	51.7 gh
Titan	55.9 ab	4.9 ab	54.9 abcd	56.9 a	5.3 ab	56.9 bc
UDP	38.4 d	3.6 d	51.9 defg	31.4 c	3.7 d	51.6 h
UDS	49.0 abcd	4.4 bcd	53.9 abcde	42.3 bc	4.5 bcd	56.0 c
LSD ($_{0.05}$)	11.5	0.9	3.2	11.5	1.0	1.9
CV%	66.9	61.3	17.2	72.0	60.4	9.7

† Cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.
‡ Quality ratings are based on the color of the colorant on a scale of 1-9.
§ Hue angles were acquired from Digital Image Analysis on a scale of 0-360°.
¶ Product Abbreviations: SWG, Southwest Green; UDP, Ultradwarf Plus; UDS, Ultradwarf Super.
# Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P=0.05).

Table 9. Visual turfgrass colorant cover and quality ratings, along with colorant hue angles following a single application of the Group 3 turf colorants on ‘Patriot’ and ‘Celebration’ bermudagrass averaged over both rates.

	2011-12			2012-13		
Treatment	Cover†	Quality‡	Hue§	Cover	Quality	Hue
Bermudagrass	42.0 a¶	3.8 a	55.9 a	5.3 c	1.3 c	50.5 a
Turf Cote	12.3 d	1.8 c	42.7 d	2.8 c	1.1 c	44.6 d
Super Cover	25.5 c	2.8 b	46.2 c	10.0 c	1.7 c	48.0 bc
Mtp Turfgreen	38.2 ab	3.7 a	49.5 b	22.3 b	2.9 b	50.3 a
Sugar Hill	29.8 bc	3.1 ab	46.3 c	32.2 a	3.7 a	49.3 ab
Southwestern	23.8 c	2.7 b	44.5 cd	5.0 c	1.3 c	46.9 c
LSD ($_{0.05}$)	10.9	0.9	2.4	7.2	0.6	1.2
CV%	109.4	81.8	14.6	159.9	92.1	7.4

† Cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.
‡ Quality ratings are based on the color of the colorant on a scale of 1-9.
§ Hue angles were acquired from Digital Image Analysis on a scale of 0-360°.
¶ Means within columns followed by the same letter are not significantly different according to Fisher’s Protected LSD (P=0.05).

Table 10. Quadratic discriminant analysis of turfgrass colorant cover, quality, and hue angle on Miniverde bermudagrass within the Group 1 colorants.

	Actual					
Predicted	Bermuda	Blue	Dye	Go Green	Regreen	Wintergreen
Bermuda	12 (7.9)†	11 (7.2)	34 (22.4)	24 (15.8)	5 (3.3)	66 (43.4)
Blue	4 (2.6)	104 (68.4)	19 (12.5)	2 (1.3)	1 (0.7)	22 (14.5)
Dye	9 (5.9)	47 (30.9)	28 (18.4)	10 (6.6)	6 (4.0)	52 (34.2)
Go Green	15 (9.9)	0 (0.0)	7 (4.6)	50 (32.9)	9 (5.9)	71 (46.7)
Regreen	14 (9.2)	8 (5.3)	12 (7.9)	46 (30.3)	11 (7.2)	61 (40.1)
Wintergreen	8 (5.26)	21 (20.9)	17 (11.2)	13 (8.6)	5 (3.3)	88 (57.9)
	Error count estimates for colorant					
Rate	0.9211	0.3158	0.8158	0.6711	0.9276	0.4211

† Values preceding parentheses represent the number of times a colorant was classified as another colorant while values within parentheses represent the percent of the total.

Table 11. Quadratic discriminant analysis of turfgrass colorant coverage, quality, and hue angle on Miniverde bermudagrass with the Group 2 colorants.

	Actual														
Predicted	Exp. 2	End	Ever	Graph	Lawn	Lesco	Line	Orig	Exp. 1	SH	SWG	Solar	Spmax	Titan	UDS
Exp. 2[‡]	7 (4.6)[†]	8 (5.3)	7 (4.6)	0 (0.0)	39 (25.7)	23 (15.1)	4 (2.6)	3 (2.0)	5 (3.3)	26 (17.1)	2 (1.3)	10 (6.6)	4 (2.63)	8 (5.3)	6 (4.0)
End	4 (2.6)	8 (5.3)	4 (2.6)	1 (0.7)	35 (23.0)	17 (11.2)	3 (2.0)	5 (3.3)	4 (2.6)	41 (27.0)	4 (2.6)	9 (5.9)	1 (0.7)	11 (7.2)	5 (3.3)
Ever	4 (2.6)	3 (2.0)	34 (22.4)	0 (0.0)	8 (5.3)	9 (5.9)	15 (9.9)	16 (10.5)	1 (0.7)	17 (11.2)	2 (1.3)	10 (6.6)	15 (9.9)	13 (8.6)	5 (3.3)
Graph	5 (3.3)	4 (2.6)	19 (12.5)	0 (0.0)	21 (13.8)	7 (4.6)	1 (0.7)	19 (12.5)	2 (1.3)	17 (11.2)	3 (2.0)	28 (18.4)	6 (4.0)	12 (7.9)	8 (5.3)
Lawn	3 (2.0)	3 (2.0)	2 (1.3)	1 (0.7)	52 (34.2)	25 (16.5)	1 (0.7)	2 (1.3)	14 (9.2)	10 (6.6)	2 (1.3)	21 (13.8)	1 (0.7)	13 (8.6)	2 (1.3)
Lesco	6 (4.0)	9 (5.9)	5 (3.3)	0 (0.0)	60 (39.5)	20 (13.2)	0 (0.0)	1 (0.7)	7 (4.6)	13 (8.6)	3 (2.0)	14 (9.2)	3 (2.0)	10 (6.6)	1 (0.7)
Line	4 (2.6)	5 (3.3)	14 (9.2)	0 (0.0)	11 (7.2)	12 (7.9)	21 (13.8)	6 (4.0)	3 (2.0)	39 (25.7)	4 (2.6)	2 (1.3)	19 (12.5)	10 (6.6)	2 (1.3)
Orig.	2 (1.3)	2 (1.3)	22 (14.5)	0 (0.0)	11 (7.2)	2 (1.3)	7 (4.6)	36 (23.7)	1 (0.7)	17 (11.2)	1 (0.7)	32 (21.1)	6 (4.0)	9 (5.9)	4 (2.6)
Exp. 1	3 (2.0)	14 (9.2)	3 (2.0)	1 (0.7)	55 (36.2)	11 (7.2)	3 (2.0)	5 (3.3)	3 (2.0)	27 (17.8)	2 (1.3)	11 (7.2)	2 (1.3)	7 (4.6)	5 (3.3)
SH	1 (0.7)	8 (5.3)	1 (0.7)	0 (0.0)	19 (12.5)	13 (8.6)	0 (0.0)	1 (0.7)	1 (0.7)	77 (50.7)	2 (1.3)	7 (4.6)	17 (11.2)	5 (3.3)	0 (0.0)
SWG	4 (2.6)	8 (5.3)	8 (5.3)	1 (0.7)	34 (22.4)	14 (9.2)	2 (1.3)	2 (1.3)	3 (2.0)	47 (30.9)	4 (2.6)	5 (3.3)	6 (4.0)	12 (7.9)	2 (1.3)
Solar	3 (2.0)	6 (4.0)	5 (3.3)	0 (0.0)	26 (17.1)	8 (5.3)	2 (1.3)	18 (11.8)	2 (1.3)	19 (12.5)	0 (0.0)	32 (21.1)	1 (0.7)	24 (15.8)	6 (4.0)
Spmax	1 (0.7)	4 (2.6)	12 (7.9)	0 (0.0)	11 (7.2)	10 (6.6)	13 (8.6)	0 (0.0)	2 (1.3)	45 (29.6)	2 (1.3)	3 (2.0)	38 (25.0)	6 (4.0)	5 (3.3)
Titan	3 (2.0)	3 (2.0)	16 (10.5)	2 (1.3)	26 (17.1)	12 (7.9)	7 (4.6)	17 (11.2)	2 (1.3)	25 (16.5)	2 (1.3)	11 (7.2)	8 (5.3)	14 (9.2)	4 (2.6)
UDS	6 (4.0)	6 (4.0)	5 (3.3)	0 (0.0)	40 (26.3)	19 (12.5)	2 (1.3)	9 (5.9)	3 (2.0)	20 (13.2)	2 (1.3)	22 (14.5)	3 (2.0)	13 (8.6)	2 (1.3)
Rate	Error count estimates for treatment														
	0.9539	0.9474	0.7763	1.0000	0.6579	0.8684	0.8618	0.7632	0.9803	0.4934	0.9737	0.7895	0.7500	0.9079	0.9868

Table 11. continued

† Values preceding parentheses represent the number of times a treatment was classified as another treatment while values within parentheses represent the percent of the total.
‡ Product abbreviations: Exp. 2, Experimental 2; End., Endurant; Ever., Evergreen; Graph., Graphics; Lawn., Lawnger; Lesco, Lesco Green; Line., Lineman; Orig., Original; Exp. 1, Experimental 1; SH., Sugar Hill; SWG, Southwest Green; Solar., Solarogen; Spmax, SprayMax; Titan, Titan Green Turf; UDS, Ultradwarf Super.

Table 12. Analysis of variance for NDVI (normalized difference vegetation index) “rub-off” data due to turfgrass colorant drag testing during February-March 2012 and 2013 at Lake Wheeler Field Laboratory in Raleigh, NC.

	Analysis of variance			
Source of Variation†	df	Mean Square	*F*	*P*>*F*
Year	1	0.04	303.48	<0.0001
Treatment	8	0.14	1188.73	<0.0001
DAA(Year)	18	0.01	56.88	<0.0001
Year × Treatment	8	0.02	154.22	<0.0001
Treatment × DAA(Year)	144	0.00	2.47	<0.0001

† Year= 2012 and 2013, Treatment= Colorant products, DAA(Year)= Days After Application (within year)

Table 13. Turfgrass colorant transfer onto a white rag recorded by normalized difference vegetation index (NDVI) as a function of time following the application of turfgrass colorants at a rate of 112 mL m^{-2} on 6 February 2012.

	NDVI reading†-days after application									
Colorant	1	2	3	4	7	10	15	22	28	35
Blue	0.233 a‡	0.234 a	0.250 a	0.239 a	0.248 a	0.223 a	0.204 a	0.147 a	0.154 a	0.141 a
No colorant	-0.004 e	-0.010 e	-0.006 g	-0.009 d	-0.008 f	-0.010 e	-0.011 e	-0.024 g	-0.025 g	-0.025 e
Endurant	0.070 bc	0.050 c	0.043 cd	0.041 c	0.041 cd	0.034 c	0.025 cd	0.015 cd	0.013 de	0.011 cd
Regreen	0.090 b	0.111 b	0.106 b	0.091 b	0.103 b	0.103 b	0.084 b	0.074 b	0.078 b	0.068 b
Solarogen	0.063 bc	0.052 c	0.044 cd	0.039 c	0.047 c	0.040 c	0.031 c	0.021 c	0.026 c	0.019 c
SprayMax	0.068 bc	0.054 c	0.058 c	0.033 c	0.039 cd	0.033 c	0.027 cd	0.015 cd	0.014 de	0.014 cd
Titan	0.052 cd	0.035 cd	0.024 f	0.026 c	0.022 de	0.018 d	0.012 d	0.004 e	0.006 ef	0.005 cd
UDS	0.033 d	0.019 d	0.025 ef	0.022 c	0.018 e	0.012 d	0.011 d	-0.008 f	-0.004 f	-0.008 ed
World Class	0.056 cd	0.053 c	0.041 de	0.040 c	0.035 cde	0.035 c	0.027 cd	0.013 d	0.017 cd	0.001 cd
LSD $_{(0.05)}$	0.03	0.02	0.02	0.03	0.02	0.01	0.02	0.00	0.01	0.02
CV%	22.7	18.4	14.9	26.8	18.8	11.7	23.3	14.1	20.7	53.5

† NDVI = ((R850 – R660) / (R850 + R660)); where R850 and R660 denote reflectance measurements at 660 and 850 nm, respectively.

‡ Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P=0.05).

Table 14. Turfgrass colorant transfer onto white recorded by normalized difference vegetation index (NDVI) as a function of time following the application of turfgrass colorants at a rate of 112 mL m^{-2} on 5 February 2013.

	NDVI reading†-days after application									
Colorant	1	2	5	7	10	15	24	30	36	43
Blue	0.113 a‡	0.147 a	0.114 a	0.115 a	0.092 a	0.102 a	0.092 a	0.072 a	0.075 a	0.064 a
No colorant	-0.002 d	-0.004 d	-0.008 d	-0.017 e	-0.017 f	-0.019 g	-0.012 f	-0.018 e	-0.020 g	-0.019 e
Endurant	0.055 b	0.049 c	0.033 bc	0.032 c	0.024 cd	0.017 e	0.014 de	0.011 c	0.005 e	0.008 d
Regreen	0.113 a	0.102 b	0.096 a	0.086 b	0.074 b	0.075 b	0.071 b	0.057 b	0.060 b	0.045 b
Solarogen	0.042 bc	0.048 c	0.040 b	0.040 c	0.036 c	0.032 c	0.032 c	0.021 c	0.020 c	0.022 c
SprayMax	0.048 bc	0.063 c	0.036 b	0.040 c	0.026 cd	0.030 cd	0.025 cd	0.017 c	0.018 cd	0.014 cd
Titan	0.060 b	0.056 c	0.031 bc	0.026 c	0.022 d	0.020 de	0.020 cd	0.014 c	0.011 de	0.013 cd
UDS	0.017 cd	0.017 d	0.013 cd	0.005 d	0.003 e	0.000 f	-0.001 ef	-0.003 d	-0.007 f	-0.007 e
World Class	0.050 b	0.049 c	0.031 bc	0.028 c	0.019 d	0.023 cde	0.020 cd	0.013 c	0.011 e	0.011 cd
LSD ($_{0.05}$)	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.0	0.01
CV%	33.8	23.8	29.9	24.6	25.2	21.5	33.2	36.8	23.0	42.1

† NDVI = ((R850 – R660) / (R850 + R660)); where R850 and R660 denote reflectance measurements at 660 and 850 nm, respectively.

‡ Means within columns followed by the same letter are not significantly different according to Fisher's Protected LSD (P=0.05).

Table 15. Analysis of variance for NDVI (normalized difference vegetation index) colorant transfer data due to turfgrass colorant drag testing. Colorants were applied at two different times based on temperature at Lake Wheeler Field Laboratory in Raleigh, NC.

	Analysis of variance			
Source of Variation†	df	Mean Square	*F*	*P*>*F*
Temperature, T	1	0.0032	90.7	<0.0001
Colorant, C	2	0.0206	586.2	<0.0001
Days After Application, D	2	0.0003	9.8	0.0004
T*C	2	0.0000	1.4	0.2618
T*D	2	0.0001	1.9	0.1721
C*D	4	0.0001	1.7	0.1976
T*C*D	4	0.0001	3.8	0.0115

† Temperature, T= Warm and cold; Colorant, C= Colorant products (Ultradwarf Super and SprayMax); Days After Application, D= Days After Application

Table 16. Analysis of variance for turfgrass colorant cover and colorant quality following a single application and sequential applications of Green Lawnger and Evergreen colorants at different intervals during two 10 week experiments at Lake Wheeler Field Laboratory in Raleigh, NC.

Analysis of variance							
		Cover			Quality		
Source of Variation†	df	Mean Square	*F*	*P>F*	Mean Square	*F*	*P>F*
Year, Y	1	1350.3	310.8	<0.001	58.1	842.1	<0.001
Treatment, T	13	1771.4	407.7	<0.001	31.8	460.5	<0.001
Week, W	9	922.5	212.3	<0.001	40.7	589.4	<0.001
Y × T	13	170.8	39.3	<0.001	1.3	19.0	<0.001
Y × W	9	299.5	68.9	<0.001	4.0	57.4	<0.001
T × W	117	267.4	61.5	<0.001	1.9	27.3	<0.001
Y × T × W	117	37.7	8.7	<0.001	0.2	3.4	<0.001

† Year, Y= 2012 and 2013; Treatment, T= Applications of Green Lawnger and Evergreen; W=Weeks after initial application.

Table 17. Visual colorant quality and cover ratings averaged over two 10 week sequential colorant application timing experiments for two turfgrass colorants applied at a rate of 112 mL m^{-2} during in 2012 and 2013 at Lake Wheeler Field Laboratory in Raleigh, NC.

	2012		2013	
Treatment†	Quality‡	Cover§	Quality	Cover
GL single application	7.9 d	87.7 f	7.3 d	77.8 h
GL 3 weeks	8.7 b	97.7 b	8.5 a	98.2 ab
GL 4 weeks	8.9 a	97.8 b	8.6 a	98.8 a
GL 5 weeks	8.9 a	97.7 b	8.5 a	97.3 bc
GL 6 weeks	8.5 b	96.8 c	8.3 b	94.8 d
GL 7 weeks	8.3 c	95.2 d	8.1 c	93.0 e
GL 8 weeks	8.2 c	93.5 e	8.0 c	91.3 f
Mil single application	6.9 h	86.7 g	6.2 g	77.8 h
Mil 3 weeks	7.9 d	98.7 a	6.9 e	99.3 a
Mil 4 weeks	7.9 de	98.0 ab	6.9 e	98.7 a
Mil 5 weeks	7.7 e	98.2 ab	6.9 e	96.2 c
Mil 6 weeks	7.4 f	96.3 c	6.7 f	94.2 de
Mil 7 weeks	7.3 fg	95.5 d	6.7 f	91.0 f
Mil 8 weeks	7.2 g	92.8 e	6.7 f	88.5 g
LSD $(_{0.05})$	0.2	0.7	0.1	1.3
CV%	3.9	1.5	2.7	2.8

† Colorant treatments are Becker Underwood-Green Lawnger (GL) and Milliken-Evergreen (Mil) applied at the same time for the first application followed by sequential applications of each colorant at 3, 4, 5, 6, 7, and 8 weeks.
‡ Quality ratings are based on the color of the colorant on a scale of 1-9.
§ Cover ratings are based on the amount of colorant present on turf foliage on a scale of 0-100.

Table 18. Percent change of dark green color index (DGCI) and hue of colorants applied to a three dimensional surface (turf) compared to a 2-dimensional surface (manila sheet) and percent change of DGCI and hue from an untreated turf plot to a colorant treated plot.

	DGCI		Hue	
Colorant Name	% change manila sheet to turf	% of untreated turf	% change manila sheet to turf	% of untreated turf
Green Lawnger	-52.3 ij	106.0 efg	-44.8 jk	41.4 hij
Lesco Green	-51.6 ij	102.8 fg	-45.5 jk	42.5 hij
Mtp Turfgreen	-53.6 j	52.8 lm	-36.2 efg	20.5 kl
Titan Green Turf	-44.8 gh	106.9 efg	-41.2 hij	47.6 fgh
Regreen	-38.7 bcdef	196.0 b	-38.3 fgh	91.4 c
Wintergreen Plus	-39.5 bcdef	178.5 c	-40.4 ghi	85.5 cd
Ultradwarf Super	-40.8 defg	101.2 fgh	-28.0 b	45.4 ghi
Ultradwarf Plus	-48.0 hi	55.1 l	-32.5 cde	25.0 k
Bermudagrass	-66.3 l	28.2 n	-52.3 l	17.7 kl
Southwest Green	-39.2 bcdef	87.4 hij	-32.9 cde	39.5 hij
Turf Cote	-54.7 j	12.5 o	-14.2 a	7.5 m
Endurant	-39.5 bcdef	85.0 ij	-28.0 b	37.0 ij
Graphics	-54.3 j	111.3 efg	-45.9 k	52.2 efg
Lineman	-50.3 ij	75.4 jk	-42.3 hijk	35.3 j
Super Cover	-61.8 k	39.5 mn	-44.6 ijk	15.8 lm
Evergreen	-40.4 cdefg	113.7 ef	-35.2 def	52.7 efg
Dye	-30.9 a	174.8 c	-31.2 bcd	102.6 b
Bermuda	-44.7 gh	154.2 d	-44.1 ijk	80.8 d
Blue	-36.1 bc	232.3 a	-38.6 fgh	121.4 a
Go Green	-41.6 efg	97.1 ghi	-36.1 ef	55.6 ef
Sugar-Hill	-35.6 b	61.8 kl	-12.1 a	18.7 kl
Original	-43.2 fg	108.7 efg	-36.5 efg	57.3 e
Southwestern	-42.0 efg	31.9 n	-14.8 a	12.2 lm
SprayMax	-36.8 bcd	101.9 fgh	-30.1 bc	39.5 hij
Solarogen	-38.7 bcde	120.1 e	-30.3 bc	60.9 e
Mean	-45.0	101.4	-35.0	48.1
Standard Deviation	9.0	54.0	10.4	29.4

Figure 1. Drag testing device developed by North Carolina State University

Figure 2. The progression of turfgrass color using actual plot photos from November 2012 to March 2013 following colorant treatment on a dormant Miniverde bermudagrass putting green at a rate of 112 mL m^{-2}.


Miniverde Bermudagrass
5 Days After Application
Untreated Control
SprayMax
Solarogen
Enviroseal Go Green
Endurant
Super Cover
Bermuda
Lineman
Ultradwarf Super
Southwestern
Southwest Green
LESCO Green
Green Lawnger
Regreen
Titan Green Turf
Turf Cote
Green Turf Dye
Sugar Hill Turf
Mtp Turfgreen
Blue
Original
Ultradwarf Plus
Graphics
Bermudagrass
Evergreen
Wintergreen Plus


Miniverde Bermudagrass
81 Days After Application
Untreated Control
SprayMax
Solarogen
Enviroseal Go Green
Endurant
Super Cover
Bermuda
Lineman
Ultradwarf Super
Southwestern
Southwest Green
LESCO Green
Green Lawnger
Regreen
Titan Green Turf
Turf Cote
Green Turf Dye
Sugar Hill Turf
Mtp Turfgreen
Blue
Original
Ultradwarf Plus
Graphics
Bermudagrass
Evergreen
Wintergreen Plus
Miniverde Bermudagrass
138 Days After Application
Untreated Control
SprayMax
Solarogen
Enviroseal Go Green
Endurant
Super Cover
Bermuda
Lineman
Ultradwarf Super
Southwestern
Southwest Green
LESCO Green
Green Lawnger
Regreen
Titan Green Turf
Turf Cote
Green Turf Dye
Sugar Hill Turf
Mtp Turfgreen
Blue
Original
Ultradwarf Plus
Graphics
Bermudagrass
Evergreen
Wintergreen Plus

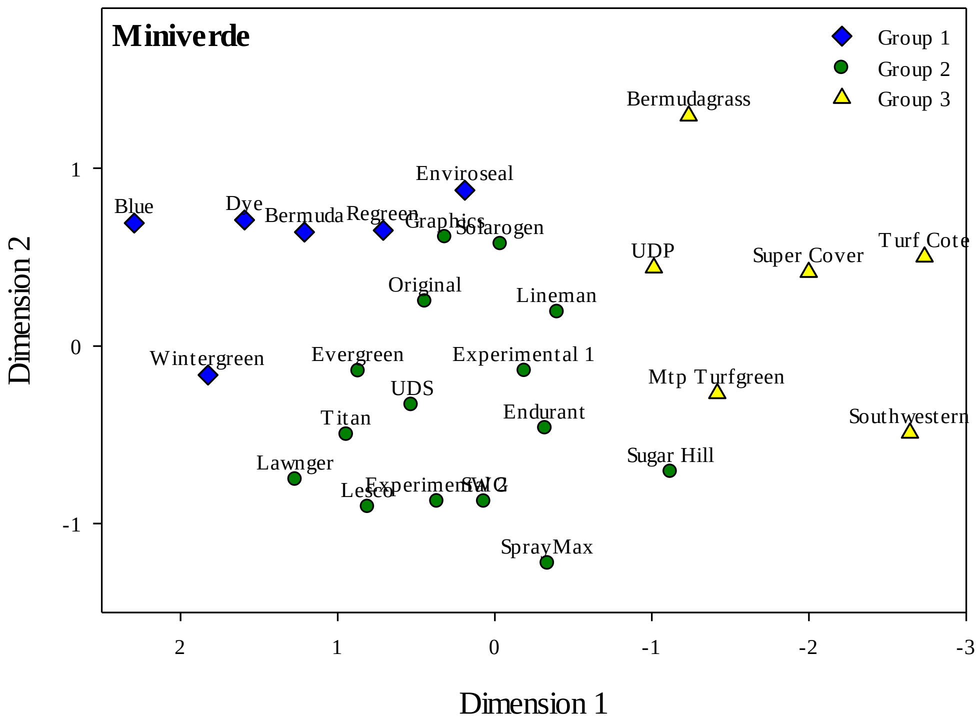


Figure 3. Multidimensional scaling (MDS) analysis scatterplot showing the clustering of twenty seven turfgrass colorants applied to Miniverde bermudagrass in 2011 and 2012 at the Lake Wheeler Field Laboratory in Raleigh, NC. MDS coordinates are clustered based on colorant coverage, quality, and hue.

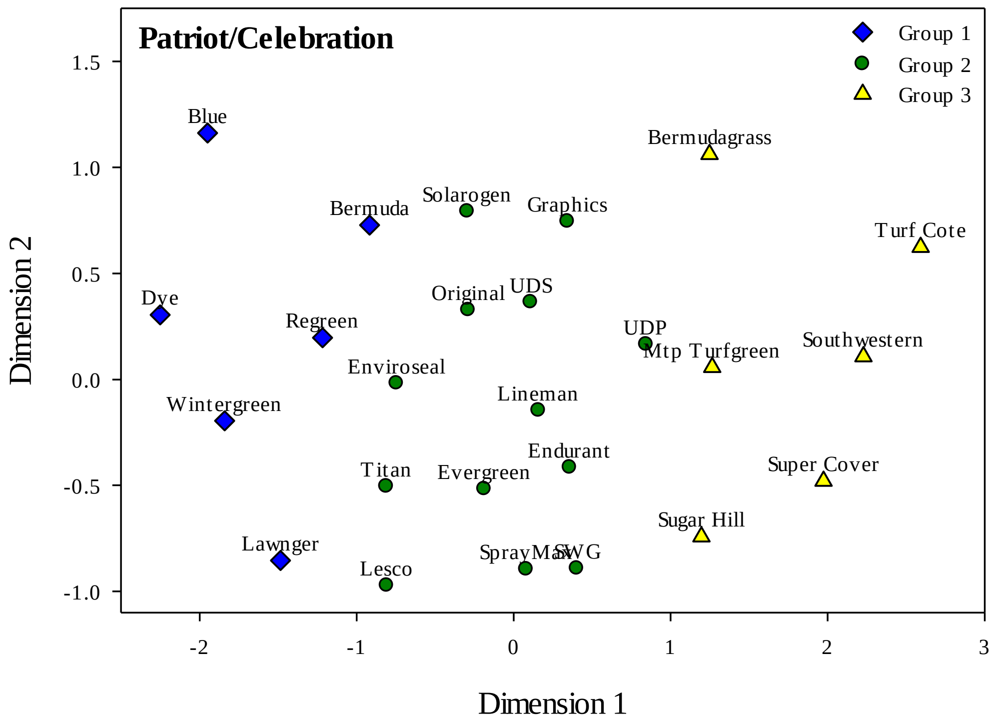
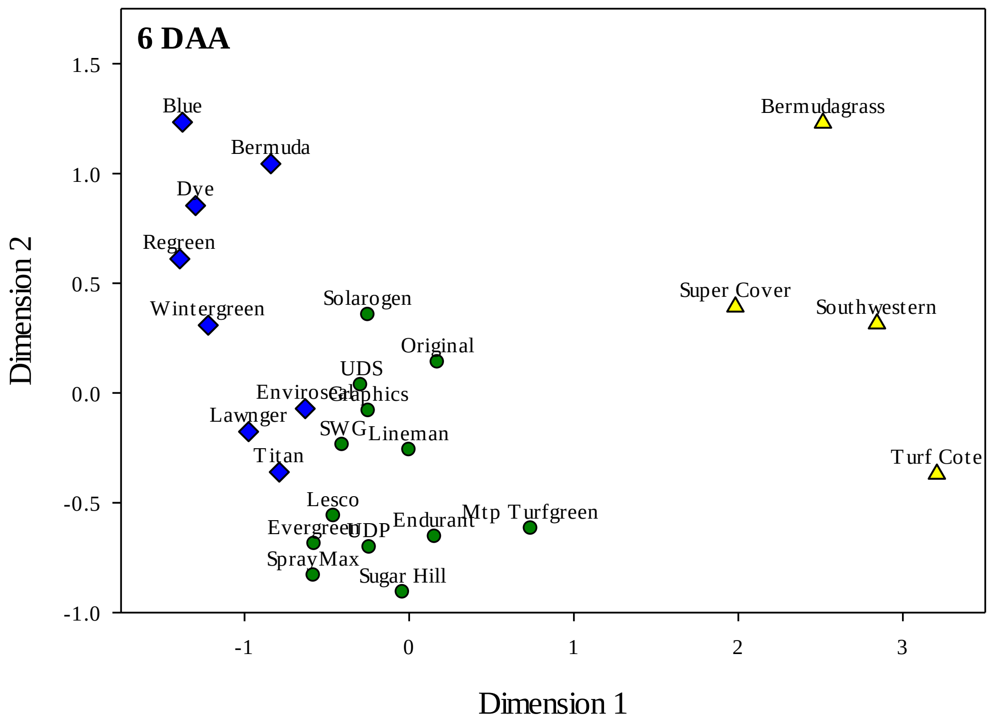
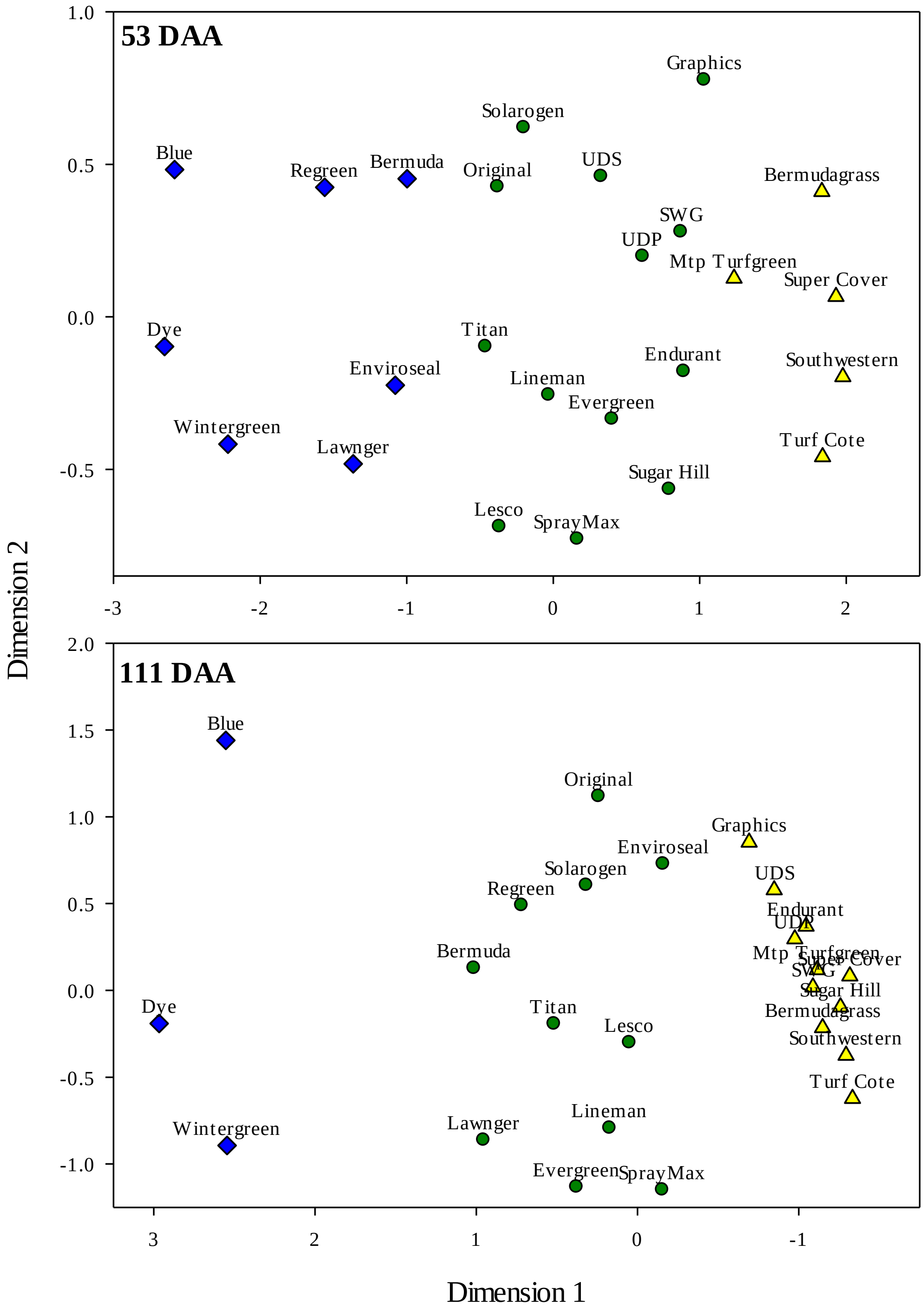


Figure 4. Multidimensional scaling (MDS) analysis scatterplot showing the clustering of twenty five turfgrass colorants applied to Patriot and Celebration bermudagrass in 2011 and 2012, respectively, at the Lake Wheeler Field Laboratory in Raleigh, NC. MDS coordinates are clustered based on colorant coverage, quality, and hue.

Figure 5. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Celebration bermudagrass at 75 mL m^{-2} in November, 2012. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 6, 53, and 111 days after application.


6 DAA
Blue
Bermuda
Dye
Regreen
Wintergreen
Solarogen
Original
UDS
Envirocolor
Graphics
Lawnger
SWG
Lineman
Titan
Lesco
Evergreen
UDP
Endurant
Mtp Turfgreen
SprayMax
Sugar Hill
Bermudagrass
Super Cover
Southwestern
Turf Cote
Dimension 2
Dimension 1
1.5
1.0
0.5
0.0
-0.5
-1.0
-1
0
1
2
3


53 DAA
Blue
Regreen
Bermuda
Original
Solarogen
Graphics
UDS
Bermudagrass
SWG
UDP
Mtp Turfgreen
Super Cover
Dye
Titan
Enviroseal
Lineman
Endurant
Southwestern
Evergreen
Wintergreen
Lawnger
Turf Cote
Sugar Hill
Lesco
SprayMax
111 DAA
Blue
Original
Graphics
Enviroseal
Solarogen
Regreen
UDS
Endurant
UDP
Bermuda
Mtp Turfgreen
Super Cover
SWG
Sugar Hill
Dye
Titan
Bermudagrass
Lesco
Southwestern
Turf Cote
Wintergreen
Lawnger
Lineman
Evergreen
SprayMax
Dimension 2
Dimension 1

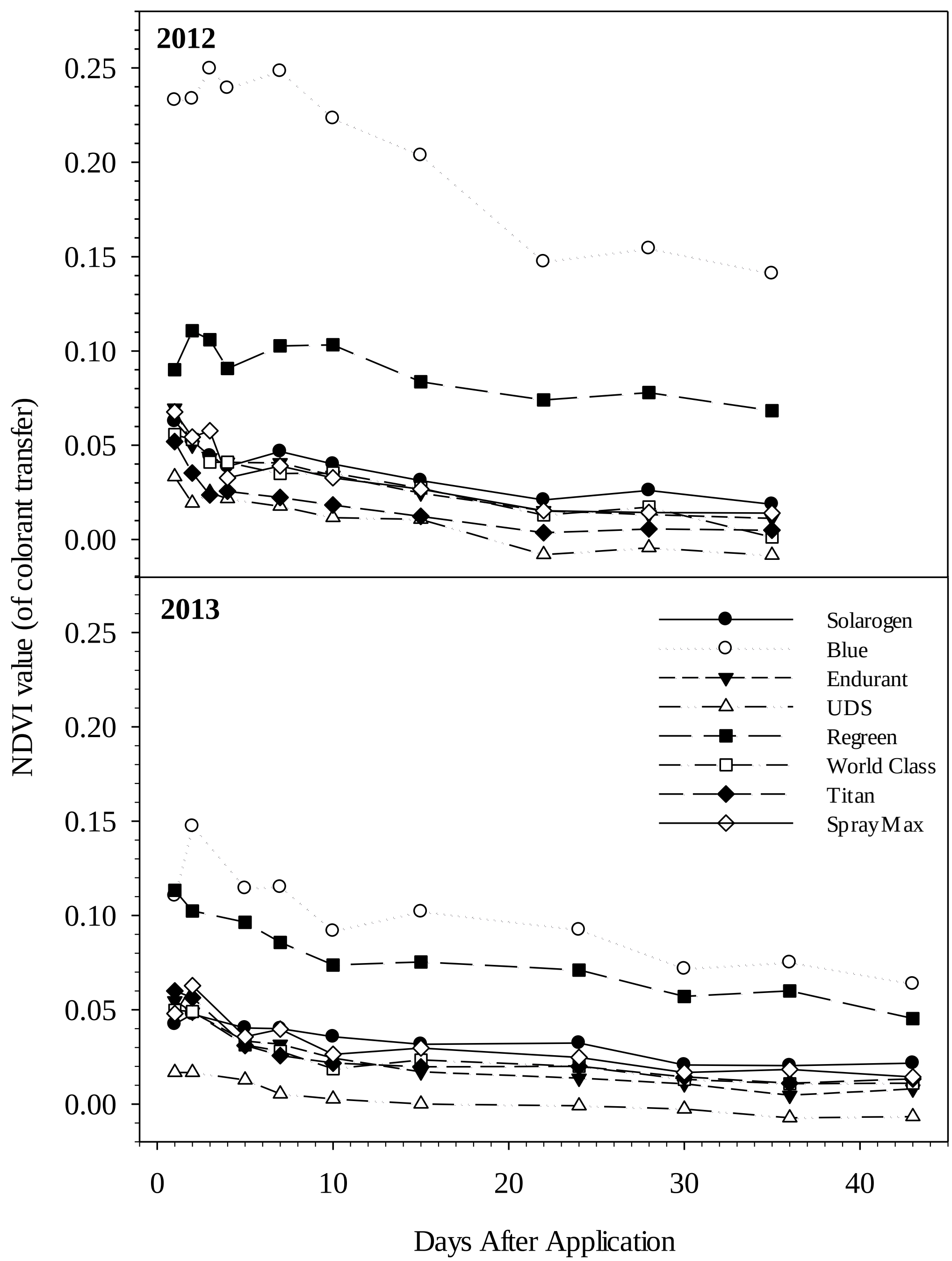


Figure 6. Turfgrass colorant transfer onto white measured by normalized difference vegetation index (NDVI) readings during February-March 2012 and 2013 at Lake Wheeler Field Laboratory in Raleigh, NC.

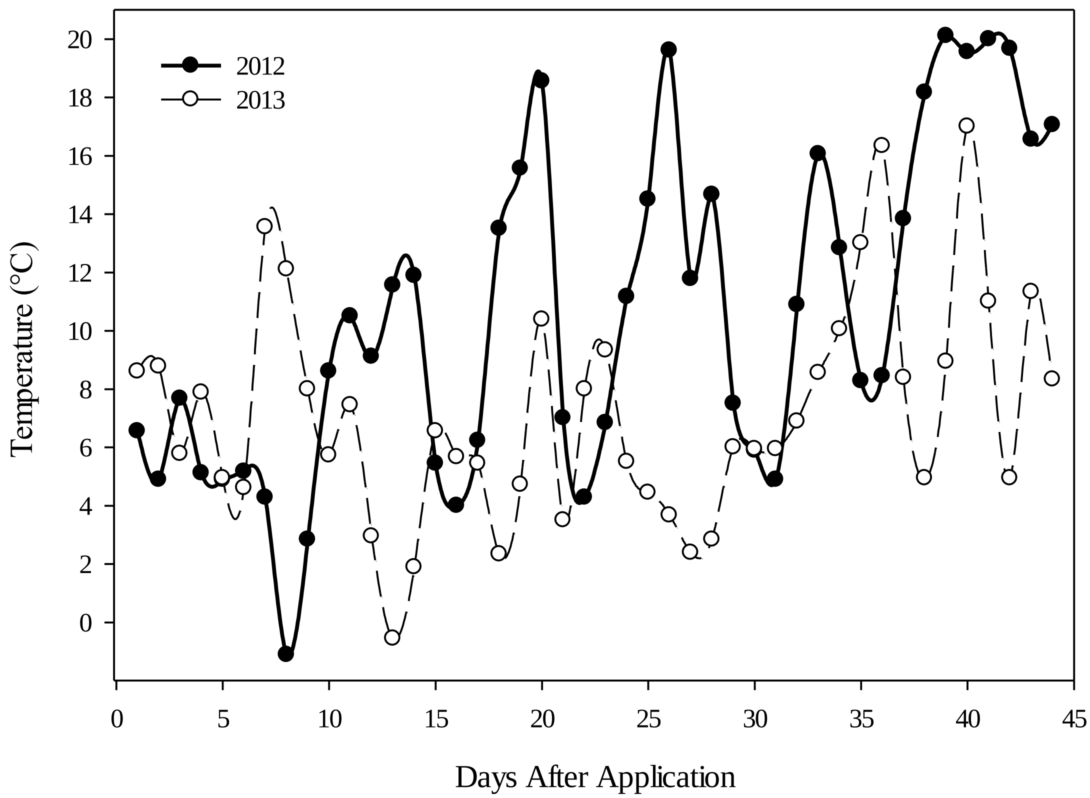


Figure 7. Daily average air temperatures (°C) recorded from initial turfgrass colorant application until 45 days after application during February-March 2012 and 2013 at Lake Wheeler Field Laboratory in Raleigh, NC.

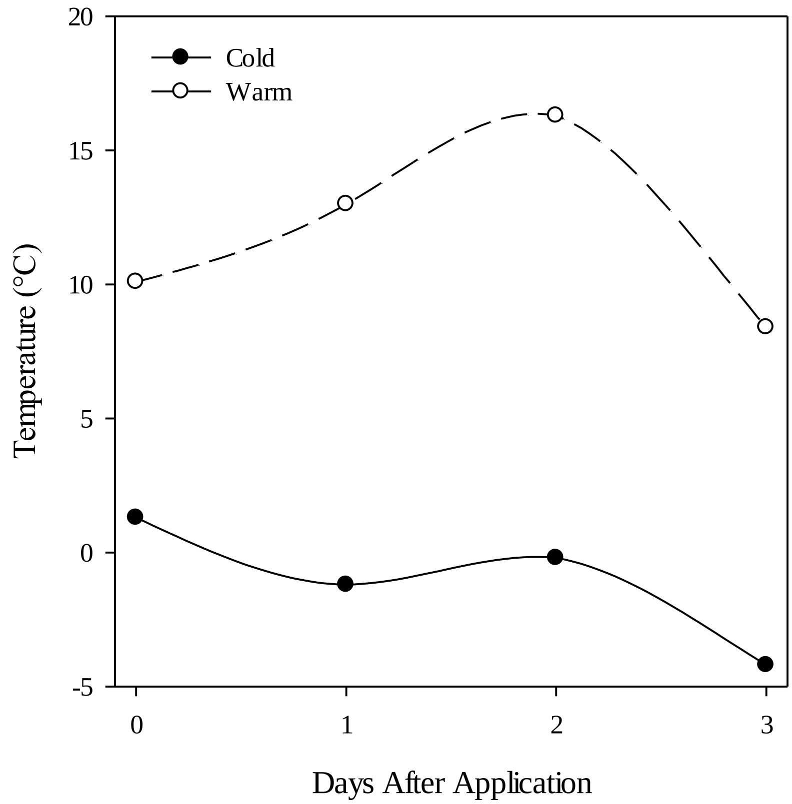


Figure 8. Daily average air temperatures (°C) recorded during both warm and cool colorant application studies at Lake Wheeler Field Laboratory in Raleigh, NC.

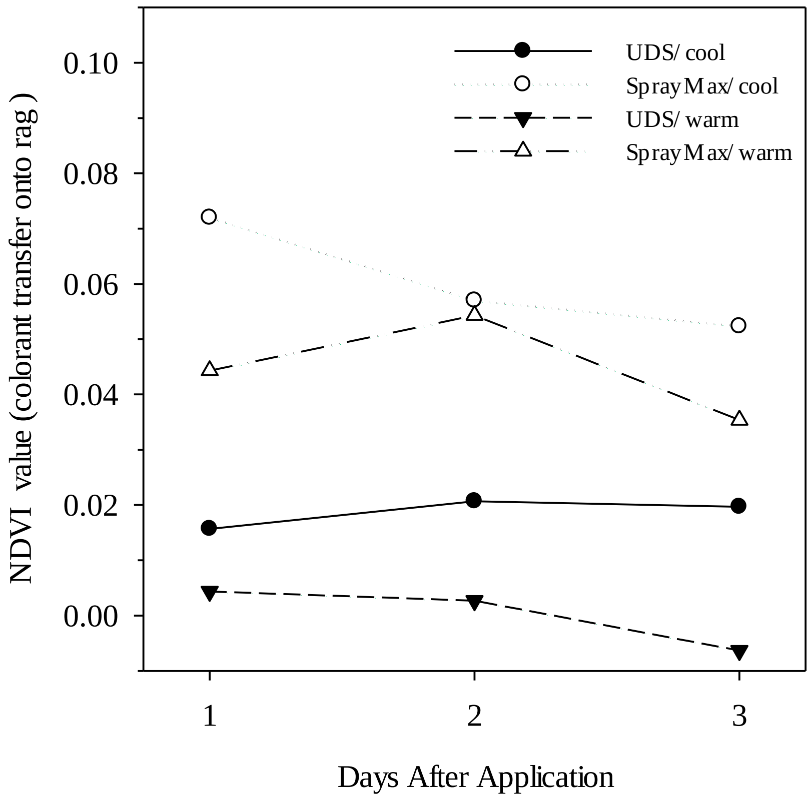


Figure 9. Turfgrass colorant "rub-off" measured by normalized difference vegetation index (NDVI) readings during two separate studies where turfgrass colorants (Ultradwarf Super, UDS and SprayMax) were applied at a temperature below 40°F (cool) and also above 60°F (warm) at Lake Wheeler Field Laboratory in Raleigh, NC.

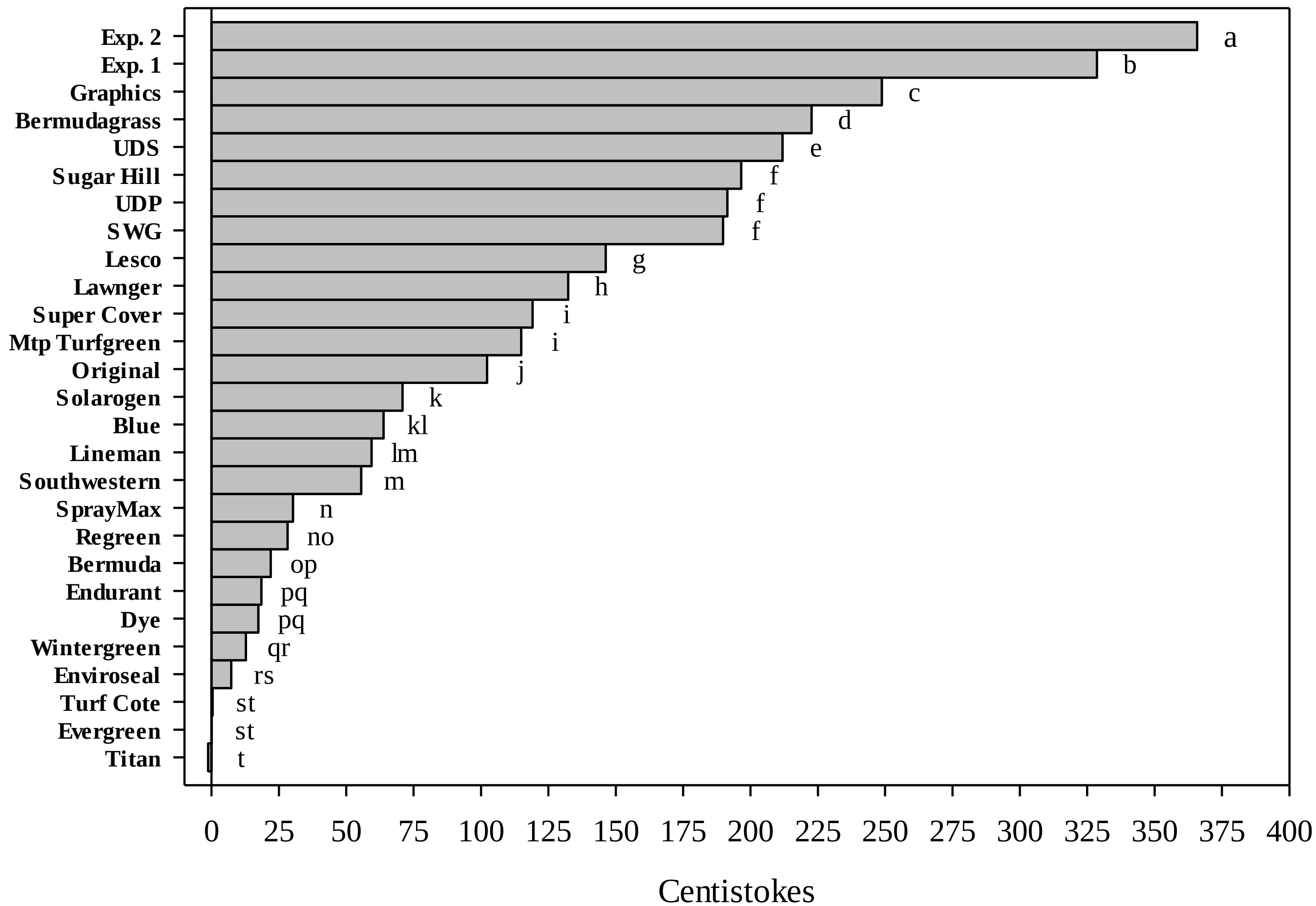
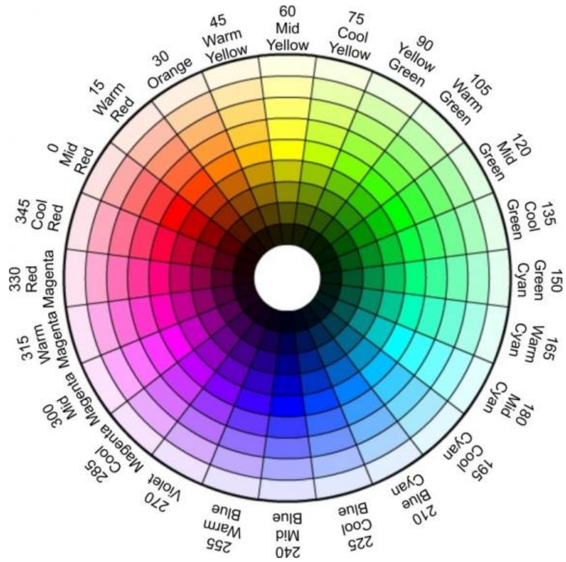


Figure 10. Viscosities of 27 non-diluted turfgrass colorants.

A.



B.

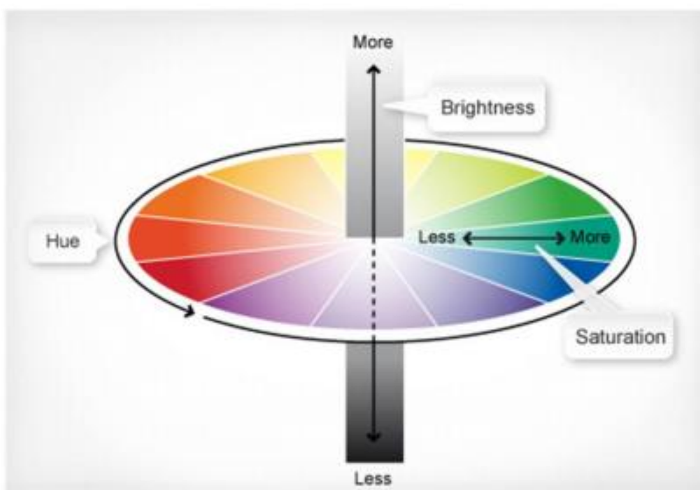


Figure 11. Color wheels showing relative hue values (A.) and hue, saturation, and brightness color space (B.). Image A available at: http://www.wetcanvas.com/forums/showthread.php?t=929022&page=3 Image B available at: http://www.westone.wa.gov.au/toolboxes/surveying/toolbox12_02/resources/images/content/pre_colour_hsbmodel.jpg

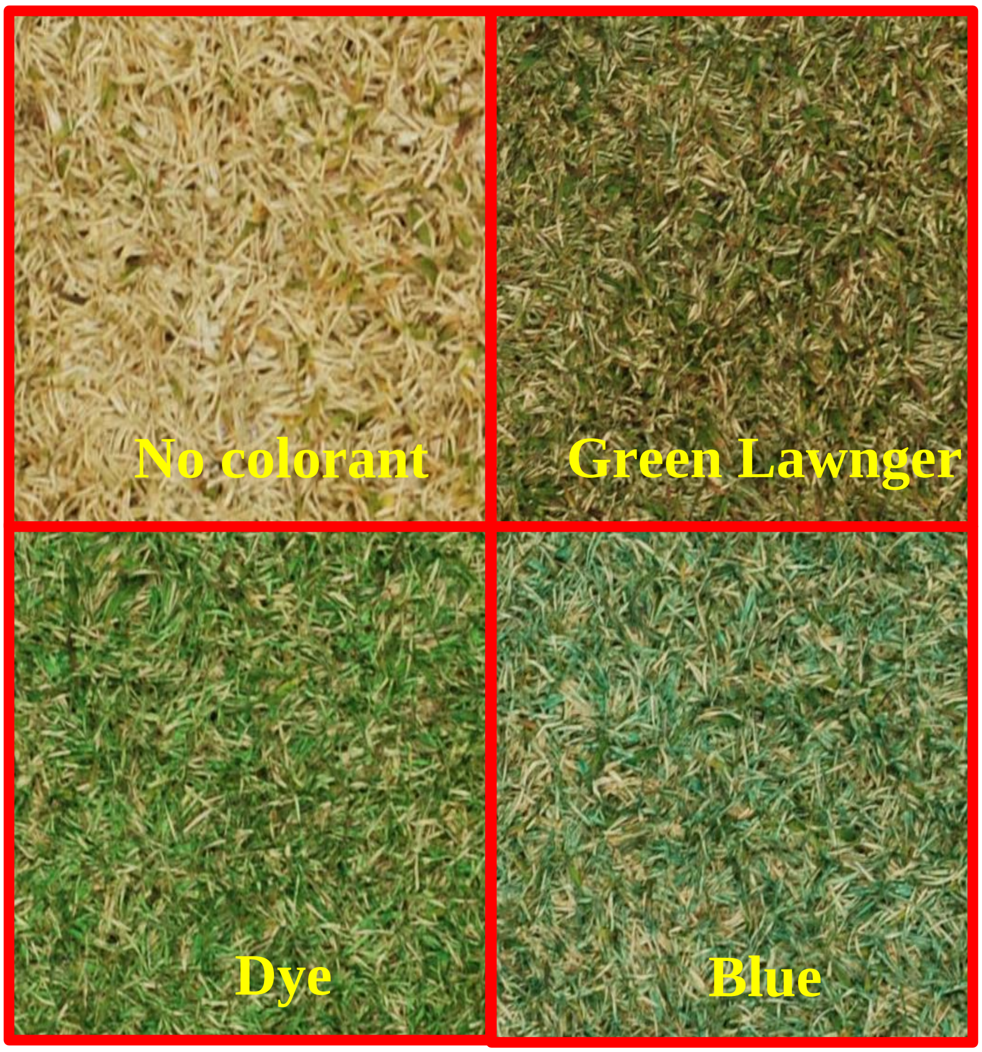


Figure 12. View of colorant coverage on dormant turf

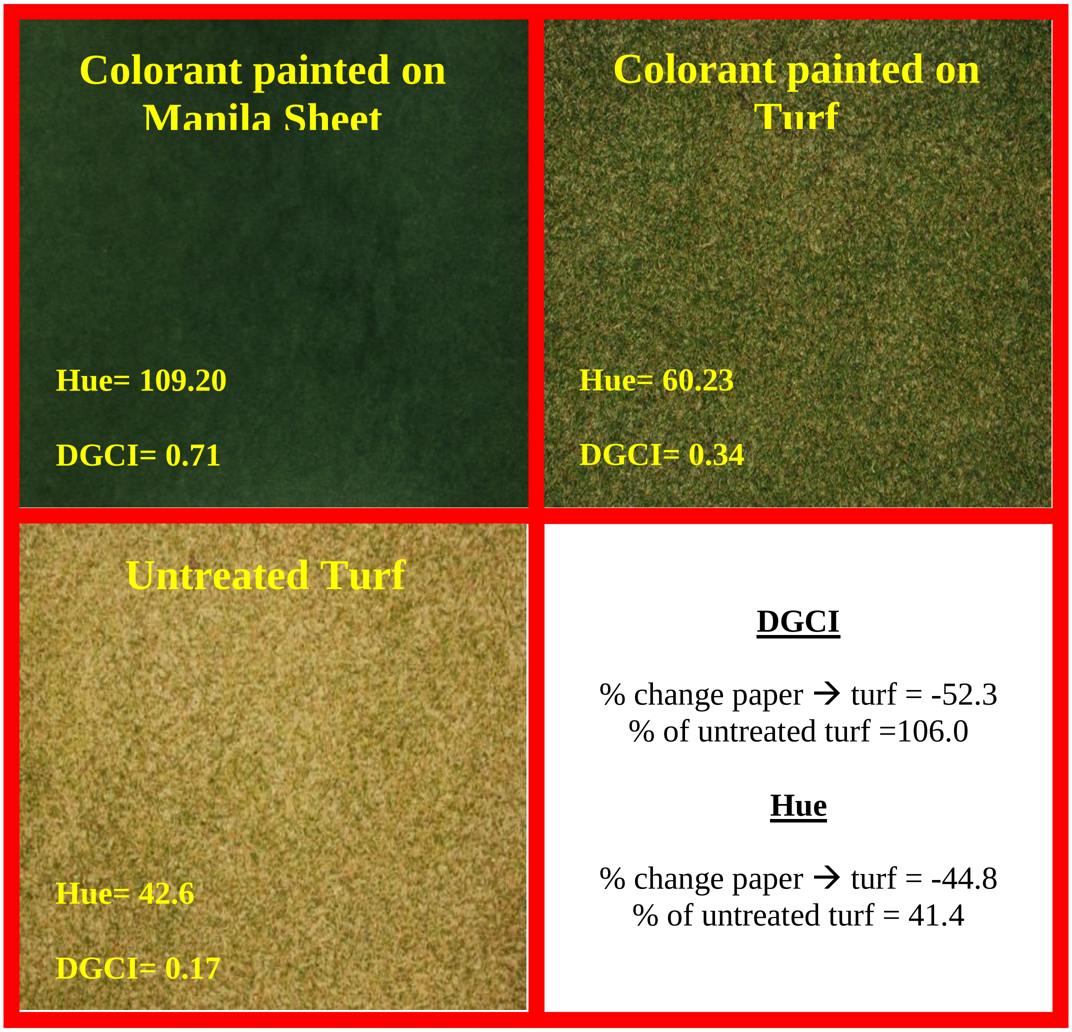


Figure 13. Comparing percent change of dark green color index (DGCI) and hue of Green Lawnger applied to a 2-dimensional surface (manila sheet) compared to a three dimensional surface (turf) and percent change of DGCI and hue from an untreated turf plot to a colorant treated plot.

CHAPTER 2

Comparison of Mowing and Athletic Paint Application Techniques

Athletic field managers routinely see declines in turfgrass health after repeated applications of athletic turf paint. The objective of this study was to evaluate the quality of a painted turf foliage and turfgrass recovery following athletic paint application timings and mowing frequencies. A field study was conducted during the summer of 2012 and winter of 2013 at the North Carolina State University Lake Wheeler Field Laboratory located in Raleigh, North Carolina. Weekly athletic paint applications were made to bermudagrass over a five week period and perennial ryegrass over a six week period. Plots were subjected to two mowing frequencies throughout the weeks. For paint quality and turfgrass recovery, differences ($P \leq 0.0001$) were noted between grasses. Athletic paint quality was from 2-12% lower when applied to bermudagrass compared to perennial ryegrass. Paint applied to bermudagrass increased by at least 11% after five weeks of paint applications compared to week one. All painting treatments provided acceptable paint quality with the exception of the 1x Wednesday treatment during week one of the study. The extra mowing cycle resulted in a lower rate of turfgrass recovery over time. Results indicated that paint quality will be greater when applied to perennial ryegrass due to reduced turfgrass growth during winter months. Furthermore, results showed that allowing an extra day of growth during weekly paint applications promoted greater turfgrass recovery.

Introduction

All sports that are played on an athletic field require the use of athletic paints to provide playing lines, logos, and other field markings. Even though logos and advertisements are not necessarily required, they are required in a time where marketing and high-definition television are at an all-time high. Consequently, painting athletic fields has become an important part of the art and science of sports field management (Kurcab, 2008).

There are a couple of ways to apply athletic paints today. The most modern athletic field painting technology in use today is an airless bulk paint spraying machine. Airless paint sprayers are able to save turf managers time with fewer paint applications while providing a painted turf canopy that is satisfactory (Anonymous, 2008). Other positives include manual pressure adjustments and drawing paint directly from the manufacturer's container. Even though applying athletic paint at high pressures can produce the best paint job possible, it may increase turfgrass stresses.

Athletic field managers routinely have issues with the health of their turf where athletic paints are frequently applied (Reynolds et al., 2012). Athletic paints primarily used today are specially formulated latex, water-based paints. Ideally, athletic paints are formulated to produce bright, uniform color in addition to being able to adhere to the turf foliage without coming off onto uniforms (Koske, 2009). It has become a common thought among athletic field managers that more is not better when it comes to painting fields (Wightman et al., 2007). An increase in the amount of paint applied will result in a brighter painted turf, but it will also cause an increase in cost for paint and labor. Perhaps, the most expensive cost associated with higher volumes of paint applied is the cost that it takes to replace paint damaged areas (Anonymous, 2008).

Recent research at North Carolina State University detailed how sequential applications of athletic turf paint can lead to a decline in plant health. Reynolds et al. (2012) studied the effects that athletic paints have on total canopy photosynthesis in perennial ryegrass (*Lolium perenne* L.). Data showed that total canopy photosynthesis was reduced based on both color and dilution of paint. This was due to the reduction of photosynthetically active radiation and degradation in light spectral quality which was a direct result of athletic field paint applications.

While research has shown repeated paint applications can lead to turf decline, identification of new paint techniques to try to negate turf decline from painting applications, has not been investigated. The purpose of this research was to examine different painting and mowing regimes to evaluate if there is a way to achieve an aesthetically pleasing paint application for a gameday and enhancing the removal of paint from the leaf.

Materials and Methods

A field study was conducted during the summer of 2012 and winter of 2013 at the North Carolina State University Lake Wheeler Field Laboratory located in Raleigh, North Carolina. Evaluations of paint application timings and mowing intervals were made based on their effect on paint quality and turfgrass recovery. The study was conducted on ‘Tifway’ bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* (Burtt-Davy)] during

July, August, and September. In a separate experimental area, Allied Seed 'ASP6002' perennial ryegrass (*Lolium perenne* L.) was seeded into 'Tifway' bermudagrass at a rate of 735 kg ha^{-1}. Treatments were applied during November, December, and January once perennial ryegrass reached 80% maturity. Turfgrass was maintained according to published guidelines (Miller et al., 2011). Over the course of five weeks from 17 July 2012 until 23 August 2012, treatments were applied to Tifway bermudagrass. Treatments on perennial ryegrass occurred from 27 November 2012 until 24 January 2013. The study was arranged in a split-block design with five randomized whole plot treatments, two sub-plot treatments and three replications. Whole plots (0.9 m × 1.8 m) included four paint application interval and rate combinations while sub-plots (0.9 m × 0.9 m) consisted of two different mowing frequencies. Due to lack of replication of grass types, the study was analyzed as a split-block in space with nested variation serving as the error term to test differences between grasses (McIntosh, 1983).

Paint rate and timing treatments included in the study were as followed:

Table 1. Weekly turf painting and mowing schedule in Raleigh, NC.

	Day of week-paint and mowing treatments			
Whole Plot (Painting)	Tuesday	Wednesday	Thursday	Friday
½x Tuesday + ½x Thursday	½		½	
1x Wednesday		x		
½x Wednesday + ½x Thursday		½	½	

Table 1. continued

1x Thursday			x	
Sub-plot (Mowing)				
TWTHF	+	+	+	+
TTHF	+		+	+

½= apply half of weekly paint; x= apply full rate of weekly paint; + = mow

Prior to painting, plots were mown to 25 mm with clipping removal. Paint used for this study was Brite Stripe Airless red athletic paint with a PMS number of 186 (Pioneer Manufacturing Co., Cleveland, OH). Treatments were applied using a Brite Striper 3000 Airless high pressure field marking machine (Pioneer Manufacturing Co., Cleveland, OH) calibrated to deliver paint at a rate of 35 mL m^{-2} with a 219 airless spray tip at 4830 kPa (700 psi). For each plot, a full 1x rate would take twenty total passes with the painting wand, resulting in a total rate of 693 mL m^{-2}.

Friday of each week was designated as the "gameday," referring to the day in which plot evaluations were made. It was important to rate plots on this day each week to see how weekly treatment combinations would look on gameday. The Friday mowing requirement and clipping removal were accomplished prior to plot evaluations each week. Paint quality evaluations were made based on the visual quality of the painted turf surface. Plots were rated on a scale of 1 to 9 (1 = no paint, 6 = acceptable paint quality, 9 = best paint quality). Percent green values were measured on a scale of 0 to 100% (0=complete paint coverage, 100=no paint coverage). High percent green values indicates the disassociation of paint from the leaf surface while a low percent green value would suggest a large amount of paint still present on the leaf.

Digital images were collected for a period of 8 weeks (20 July 2012 through 13 September 2012) during the summer and for 13 weeks (30 November 2012 through 21 February 2013) during the winter. Digital photographs were taken for a longer period of time compared to the visual paint quality ratings in order to monitor residual paint on the turfgrass leaf surface over time. Evaluations lasted longer in the winter due to adverse weather preventing paint application and mowing treatments during certain weeks.

Digital images were captured using a Nikon D80 digital camera (Nikon Inc., Melville, N.Y.) in jpeg format under consistent lighting to avoid any alterations in light due to cloud cover or shadowing (Ikemura, 2003). Camera settings were manually adjusted to ensure equal capture conditions for images taken throughout the study and were set to an aperture setting of f/5.6, a shutter speed of 1/50 second, and a focal length of 30 mm. The sizes of the images collected were "small" and equal to a pixel count of 1,936 × 1,296. Images were downloaded to a computer for analysis that used a macro developed with ImageJ software (National Institutes of Health, Bethesda, Md.) to extract the percent green within each photograph. A threshold of pixel values was unique for each data collection to account for change in green color over time.

All statistical analyses were performed using Statistical Analysis System (version 9.3, 2012; SAS Institute Inc., Cary, NC). Athletic paint quality and percent green turf were subjected to analysis of variance to determine treatment effects and treatment interactions.

Mean separation procedures were subjected to Fisher's Protected LSD test at the 0.05 probability level.

Results and Discussion

Results indicate that grass species and paint treatment were significantly different ($P \leq 0.0001$) when rating the quality of the painted surface. Also, grass species and mowing were significantly different when evaluating turfgrass recovery (Table 2). Paint quality across all painting treatments was 8% lower on bermudagrass compared to perennial ryegrass. Furthermore, paint quality was 2, 7, 9, and 12% lower with paint treatments 1x Thursday, ½x Wednesday + ½x Thursday, ½x Tuesday + ½x Thursday, and 1x Wednesday, respectively when applied to bermudagrass compared to perennial ryegrass (Table 3). This decline in paint quality can be attributed to turfgrass growth habits and the vigorous growth of bermudagrass during July and August. The low paint quality for the 1x Wednesday paint treatment (Table 3) also agrees with Reynolds et al. (2012) who found that turfgrass photosynthesis was reduced with plants coated with athletic turf paint. Due to the 1x Wednesday paint treatment being able to disassociate from the turf foliage faster, this would allow for an increase of light capture by the leaf. Increased light capture could potentially lead to increased growth resulting in lower paint quality. Figure 1 shows paint quality following paint applications on bermudagrass. Paint treatments accompanied with mowing on T, TH, and F (TTHF) had an increase in paint qualities of 13, 17, 17, and 19%, for 1x Thursday, ½x Wednesday + ½x Thursday, ½x Tuesday + ½x Thursday, and 1x Wednesday, respectively after five weeks of athletic paint application compared to week one. Paint treatments accompanied with mowing on T, W, TH, and F (TWTHF) had increases in paint qualities of 11, 15, 19, and 19%, for 1x Thursday, ½x Wednesday + ½x Thursday, ½x Tuesday + ½x Thursday, and 1x Wednesday, respectively after five weeks of athletic paint application compared to week one. Figure 1 shows that paint quality does not dramatically change after the second application of athletic paint suggesting that after initial painting, managers could begin to apply smaller amounts of paint and sustain quality. This is due to residual paint accumulated within the turf canopy from previous applications. Figure 2 shows the constant paint quality over time when applied to perennial ryegrass. With the exception of the 1x Wednesday treatment on 12/14/12 paint quality is constant from day 1 until the end of paint application, suggesting that field managers are able to apply smaller amounts of paint during the end of sports seasons and still achieve a quality painted surface. This will also reduce the amount of paint accumulated in the thatch and turf foliage that will promote a faster spring transition.

Percent green values show how a turf is able to recover after applications of turf paint. As expected, table 3 illustrates how bermudagrass recovers faster than perennial ryegrass. The extra mowing on Wednesday yielded a higher percent green value when evaluated on bermudagrass but when monitored over time, turfgrass recovery was insignificant (Table 4). Although different mowing intervals had minimal effect on overall turfgrass recovery for bermudagrass, recovery was 15% greater for the TTHF mowing treatment after paint applications ended (Table 4). This suggests allowing turfgrass an extra day of growth during the week of an event will promote higher turfgrass recovery over time.

High coefficient of variation percentages can be attributed to the mean values being near zero causing sensitivity to small changes in the mean.

Figure 3 illustrates the trends of different painting treatments under two mowing frequencies and their similarity in bermudagrass recovery. The 1x Wednesday painting treatment resulted in higher bermudagrass recovery (percent green) during the five weeks of painting due to the full rate of paint being exposed to the most mowing cycles, which as previously, mentioned, led to a decrease in paint quality. Perennial ryegrass recovery also showed differences between the two mowing cycles during the time of recovery (Table 5). Although overall percent green values show no differences, there was a higher recovery rate seen with the TTHF mowing treatment (0.4-26.2%) compared to the TWTHF treatment (0.5-25.7%), mimicking what was found for bermudagrass.

Figure 4 shows minimal differences for perennial ryegrass recovery for the four paint treatments between the two mowing frequencies. A possible explanation for the TWTHF mowing having lower turfgrass recovery for 1x Thursday and ½ x Wednesday + ½ x Thursday paint treatments could be due to the turf being shorter prior to application resulting in more paint reaching lower in the canopy. Paint that reaches lower in the canopy will persist longer due to being out of reach of the mower. Furthermore, the TTHF mowing had higher turfgrass recovery due to taller turf preventing the paint from reaching lower in the canopy, allowing the mower to remove the paint from the plant.

Conclusions

Athletic paint quality was greater when applied to perennial ryegrass compared to bermudagrass for all painting and mowing treatments. A higher paint quality can be attributed to the lack of vigorous growth seen in perennial ryegrass during winter months allowing for paint to persist longer on the leaf surface by not being mown off as quickly. Furthermore, it was seen where painting treatment 1x Thursday produced the highest paint quality for both grasses, followed by ½x Wednesday + ½x Thursday, ½x Tuesday + ½x Thursday, and 1x Wednesday, respectively. With exception of 1x Wednesday during the first week of painting, all of the painting treatments were considered acceptable for the remainder of the study. Depending on the quality of paint required for the given event all of the painting treatments tested in this study could be successfully implemented.

The mowing frequencies had minimal influence on overall turfgrass recovery in this study, but when comparing recovery for mowing treatments following painting, the TTHF mowing treatment yielded a higher recovery rate. The data shows that an extra day of mowing leading up to a gameday will not promote a significant amount of turfgrass recovery. The extra day of growth during the week allows the plant to keep more of the paint in the top of the canopy that is exposed to mowing as opposed to allowing the paint to penetrate lower into the canopy and out of reach of the mower.

LITERATURE CITED

Anonymous. 2008. Field painting advice from suppliers. SportsTurf. 24(7):34, 36, 38.

Miller, G.L., C.H. Peacock, M. Martin, A.H. Bruneau, F.H. Yelverton, L.P. Tredway, R.L. Brandenburg, and C. Reynolds. 2011. Carolina Athletic Fields: A Guide to Maintaining Quality Turf on Athletic Fields, AG 476, NCSU Crop Science Extension, Box 7620, N.C. State University, Raleigh, NC 27695-7620

Ikemura, Y. 2003. Using digital image analysis to measure the nitrogen concentration of turfgrasses. MS thesis. University of Arkansas, Fayetteville, AR.

Koske, Thomas J. 2009. Painting athletic turf [Online]. LSUAgCenter, Baton Rouge, LA. Available at http://www.lsuagcenter.com/en/lawn garden/commercial horticulture/turfgrass/athletic fields/Painting+Athletic+Turf.htm (verified 03/09/2013).

Kurcab, R. 2008. Field painting 101: Do's and don'ts to improve your technique. SportsField Manage. 3(4):7-10.

McIntosh, M.S. 1983. Analysis of combined experiments. Agron. J. 75:153-155

Reynolds, W. C., G. L. Miller, and T. W. Rufty. 2012. Athletic field paint impacts light spectral quality and turfgrass photosynthesis. Crop Sci. 52(5):2375-2384.

SAS Institute. 2013. The SAS system for Microsoft Windows, version 9.3. SAS Inst., Cary, NC.

Wightman, S., B. Campbell, and T. Leonard. 2007. Top 5 painting recommendations, Part 1. SportsTurf. 23(7):28-34

Table 2. Athletic turf paint quality and % green due to different paint application and mowing timings on Tifway bermudagrass and ASP6002 perennial ryegrass at Lake Wheeler Field Laboratory in Raleigh, NC.

		Analysis of variance					
		Paint Quality‡			% Green§		
Source of † Variation	df	Mean Square	*F*	*P>F*	Mean Square	*F*	*P>F*
Grass, G¶	1	29.8	42.7	<0.001	110521.9	7267.2	<0.001
Replication(G), R	4	0.7	2.1	0.0842	15.2	0.0	0.9981
Paint, P#	3	24.2	171.0	<0.001	55.4	0.5	0.7142
P*G	3	2.3	6.8	0.0002	26.4	0.1	0.9830
Mow, M††	1	0.0	1.5	0.2864	156.9	12.9	0.0229
M*P‡‡	3	0.0	0.4	0.7354	34.6	1.2	0.3582
M*G	1	0.1	2.3	0.1315	172.4	0.4	0.5488
M*G*P	3	0.1	0.4	0.7572	21.8	0.1	0.9871

† G= Tifway bermudagrass and perennial ryegrass, P= four paint treatments, M= two mowing treatments, R= replication (nested replication within grass)
‡ Paint quality was rated on a scale of 1-9, with 9 being a dark red color
§ Percent green was measured through Digital Image Analysis (DIA)
¶ For testing effect of G, nested replication was used as the error term.
# For testing effect of P, the P*R means square was used as the error term.
†† For testing effect of M, the M*R means square was used at the error term.
‡‡ For testing effect of M*P, the M*P*R means square was used at the error term.

Table 3. Athletic paint quality and percent green means of four painting treatments applied at different treatment regimes on 'Tifway' bermudagrass and perennial ryegrass.

	Paint quality means†-paint treatments			
Turfgrass	½x Tuesday + ½x Thursday	1x Wednesday	½x Wednesday + ½x Thursday	1x Thursday
Bermudagrass	7.9 b‡	6.9 b	8.2 b	8.8 a
Perennial Ryegrass	8.7 a	8.0 a	8.9 a	8.9 a
	% Green means†			
Bermudagrass	31.2 a	33.3 a	31.0 a	31.9 a
Perennial Ryegrass	3.5 b	3.6 b	2.9 b	3.0 b

† Treatment means averaged over dates.
‡ Mean separations are within paint treatment columns.

Table 4. Tifway bermudagrass recovery (percent green) as a result of two mowing intervals following sequential applications of red athletic paint. Time of painting denotes the weeks in which paint was applied followed by time of recovery when no paint was applied.

Mowing[‡] Treatment	Percent Green Foliage[†]-by date							
	Time of Painting					Time of Recovery		
	7/20	7/27	8/3	8/17	8/24	9/1	9/6	9/13
	% green							
TWTHF	1.7 a[§]	2.0 a	0.5 a	0.8 a	0.5 a	40.8 a	59.8 a	63.3 a
TTHF	2.2 a	2.0 a	0.4 a	0.8 a	0.4 a	35.0 b	57.2 a	59.5 a
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS
CV%	149.0	107.6	107.2	131.0	107.6	13.7	8.9	10.7

† Percent green was measured through Digital Image Analysis (DIA) on a scale of 0-100.
‡ TWTHF=Tuesday, Wednesday, Thursday, and Friday; TTHF=Tuesday, Thursday, and Friday
§ Values with the same letter within each date are not significantly different according to Fisher's $LSD_{(0.05)}$ test.

Table 5. Perennial ryegrass recovery as a result of two mowing intervals following sequential applications of red athletic paint. Time of painting denotes the weeks in which paint was applied followed by time of recovery when no paint was applied.

Mowing[‡] Treatment	Percent Green Foliage[†]-by date								
	Time of Painting						Time of Recovery		
	11/30	12/7	12/14	12/21	1/12	1/25	2/1	2/7	2/21
	% green								
TWTHF	0.2 a[§]	0.0 a	0.1 a	0.1 a	0.2 a	0.0 a	0.5 a	2.4 a	25.7 a
TTHF	0.1 a	0.0 a	0.1 a	0.0 b	0.1 a	0.0 a	0.4 a	2.4 a	26.2 a
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	95.9	119.1	99.1	51.2	46.6	121.4	72.2	44.2	18.1

† Percent green was measured through Digital Image Analysis (DIA) on a scale of 0-100.
‡ TWTHF=Tuesday, Wednesday, Thursday, and Friday; TTHF=Tuesday, Thursday, and Friday
§ Values with the same letter within each date are not significantly different according to Fisher's $LSD_{(0.05)}$ test.

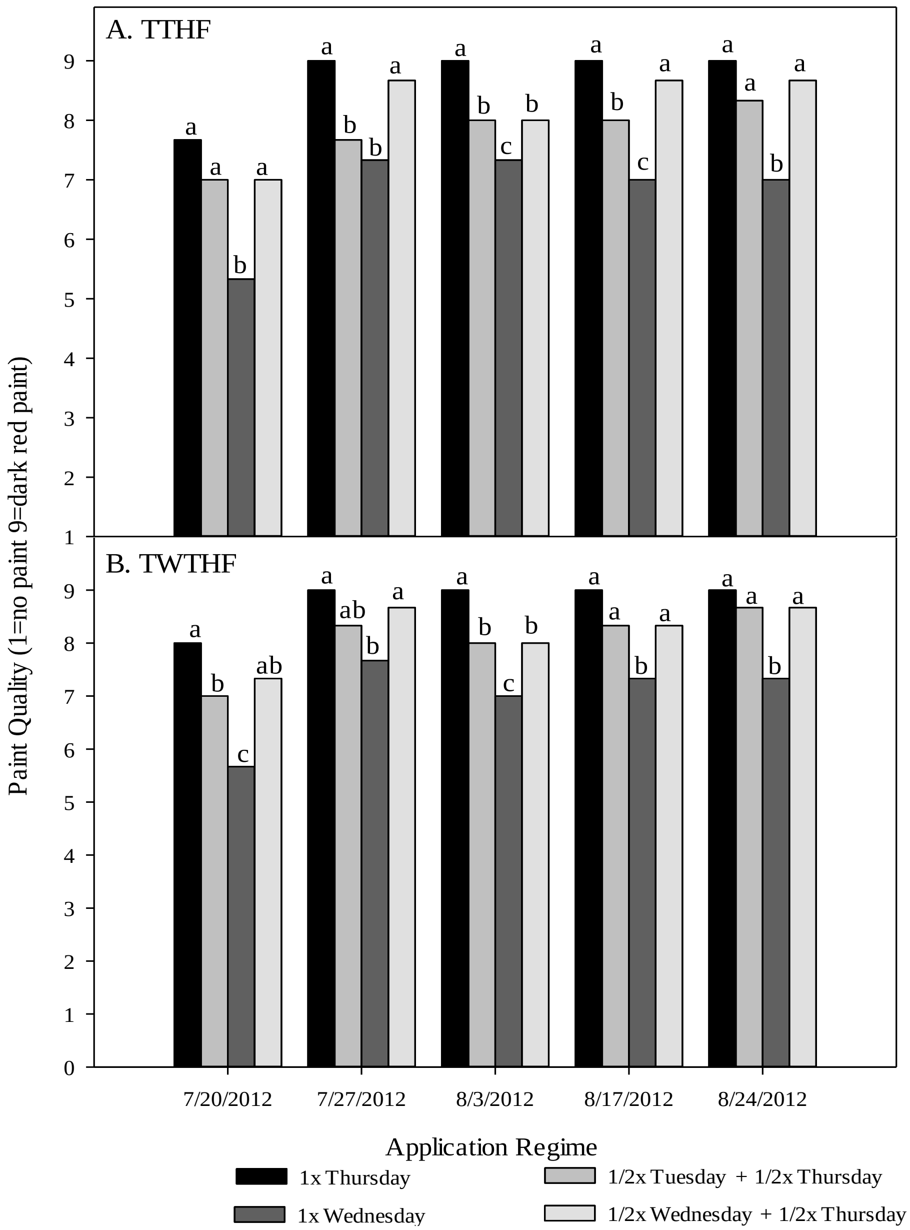


Figure 1. Effect of red athletic paint application regimes on paint quality applied to Tifway bermudagrass mowed at two intervals A. TTHF (mowing on Tuesday, Thursday, and Friday) B. TWTHF (mowing on Tuesday, Wednesday, Thursday, and Friday). Values with the same letter within each date are not significantly different according to Fisher's $LSD_{(0.05)}$ test. Rating days are Friday of each week.

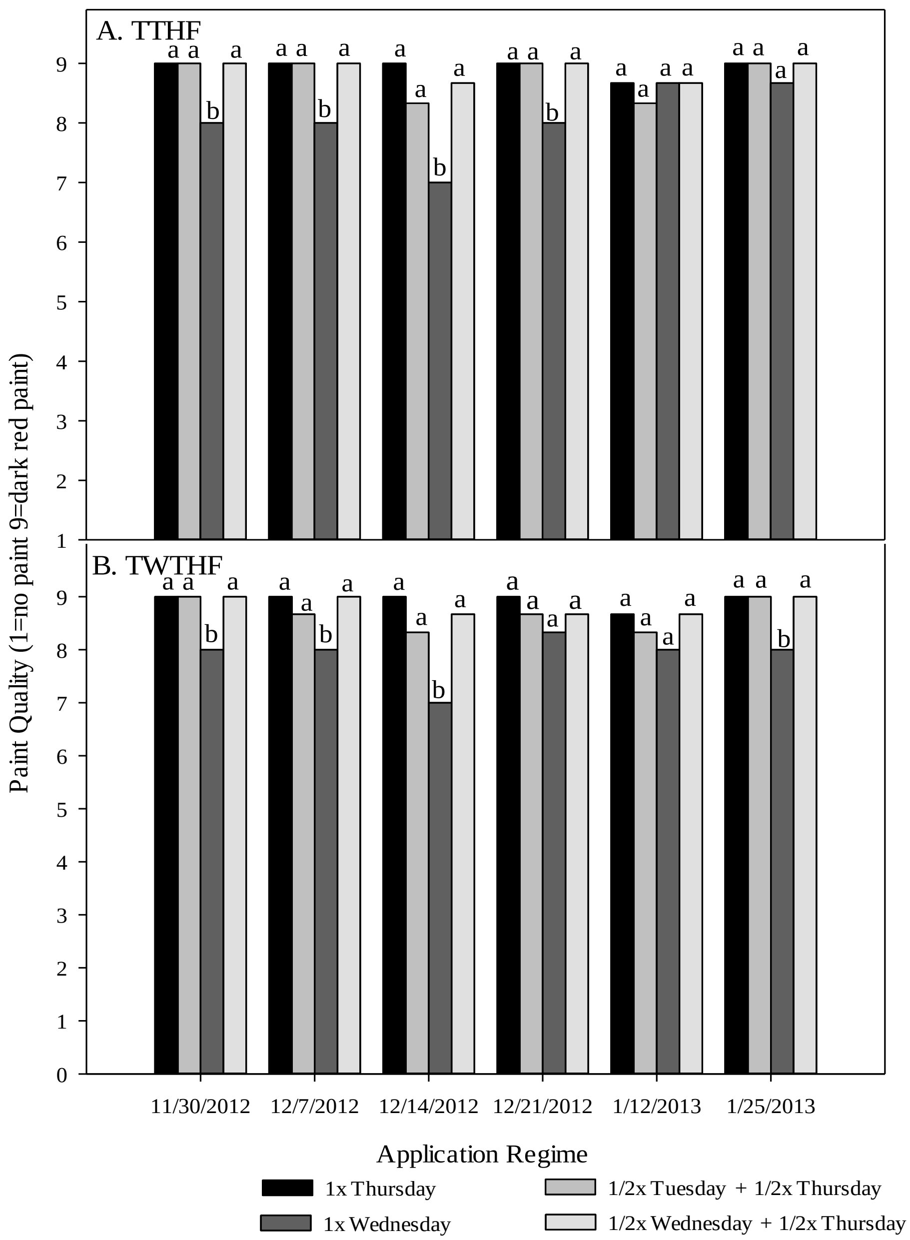


Figure 2. Effect of red athletic paint application regimes on paint quality applied to perennial ryegrass mowed at two intervals. A. TTHF (mowing on Tuesday, Thursday, and Friday) B. TWTHF (mowing on Tuesday, Wednesday, Thursday, and Friday). Values with the same letter within each date are not significantly different according to Fisher's LSD($_{0.05}$) test. Rating days are Friday of each week.

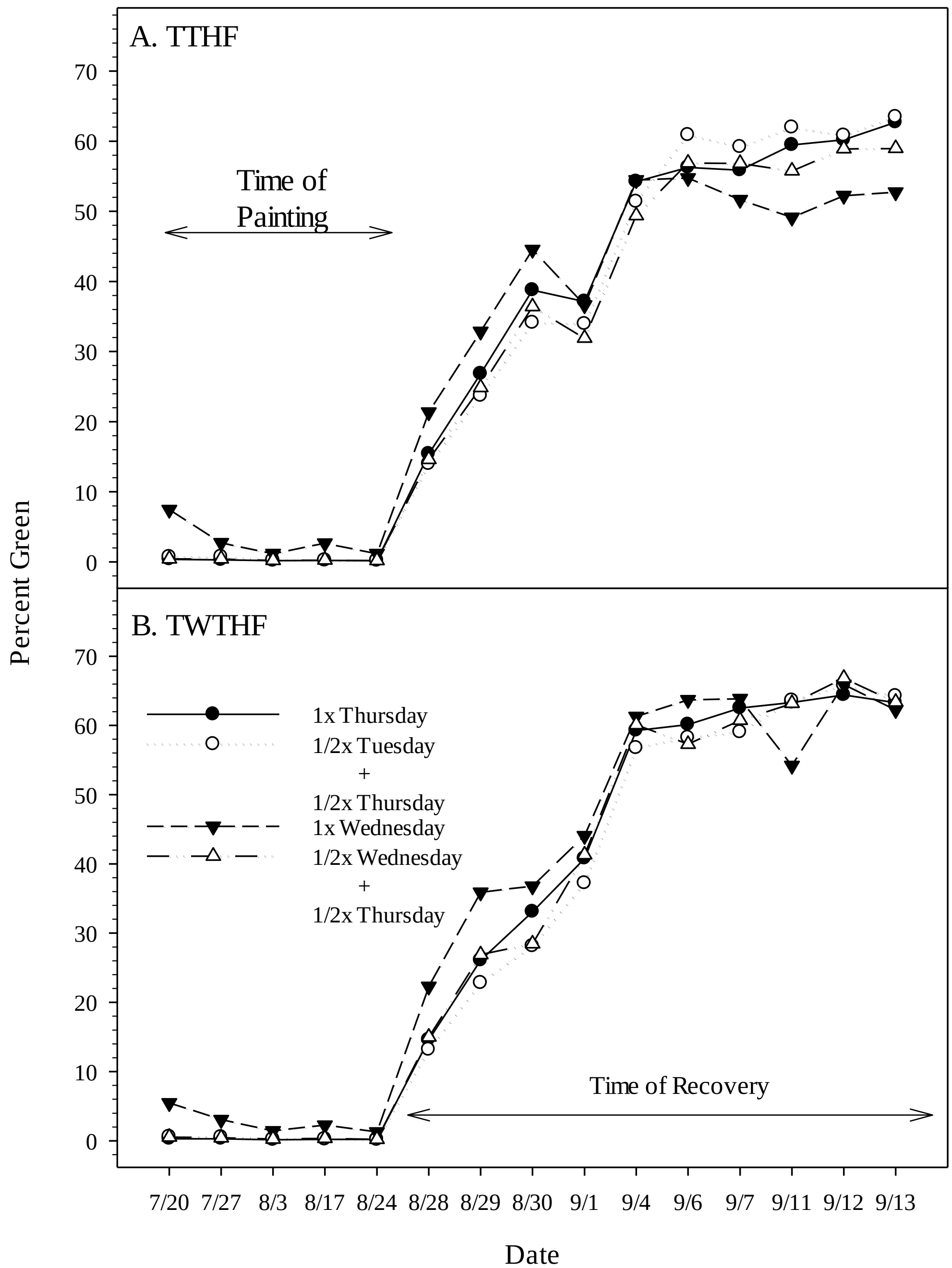


Figure 3. Effect of red paint application regimes on turfgrass recovery from repeated athletic paint applications applied to 'Tifway' bermudagrass. A. TTHF (mowing on Tuesday, Thursday, and Friday) B. TWTHF (mowing on Tuesday, Wednesday, Thursday, and Friday).

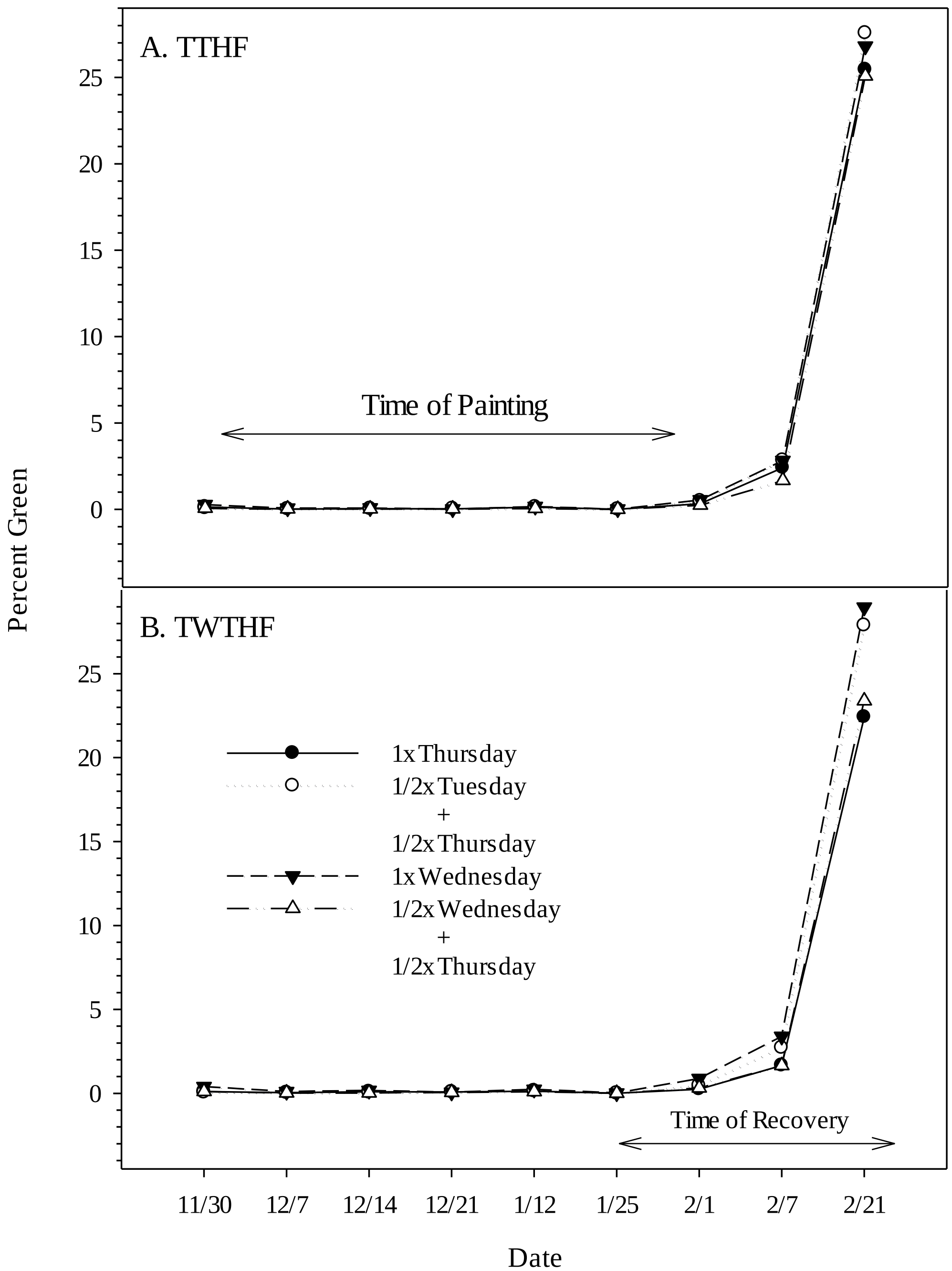


Figure 4. Effect of red athletic paint application regimes on turfgrass recovery from repeated athletic paint applications applied to perennial ryegrass. A. TTHF (mowing on Tuesday, Thursday, and Friday) B. TWTHF (mowing on Tuesday, Wednesday, Thursday, and Friday).

APPENDICES

Appendix A

Additional Quadratic Discriminant Analysis Tables

Table 1. Quadratic discriminant analysis of turfgrass colorant cover, quality, and hue angle on Miniverde bermudagrass within the Group 3 colorants tested at the Lake Wheeler Field Laboratory in Raleigh, NC.

	Actual					
Predicted	Bermudagrass	Turf Cote	Super Cover	Mtp Turfgreen	Southwestern	Ultradwarf Plus
Bermudagrass	63 (41.5)	56 (36.8)	5 (3.3)	9 (5.9)	4 (2.6)	15 (9.9)
Turf Cote	10 (6.6)	112 (73.7)	6 (4.0)	14 (9.2)	3 (2.0)	7 (4.6)
Cover	26 (17.1)	70 (46.1)	5 (3.3)	23 (15.1)	9 (5.9)	19 (12.5)
Mtp Turfgreen	21 (13.8)	58 (38.2)	10 (6.6)	24 (15.8)	7 (4.6)	32 (21.1)
Southwestern	8 (5.3)	107 (70.4)	5 (3.3)	15 (9.9)	1 (0.7)	16 (10.5)
Ultrdwarf Plus	31 (20.4)	47 (30.9)	8 (5.3)	23 (15.1)	6 (4.0)	37 (24.3)
	Error count estimates for treatment					
Rate	0.5855	0.2632	0.9671	0.8421	0.9934	0.7566

† Values preceding parentheses represent the number of times a treatment was classified as another treatment while values within parentheses represent the percent of the total.

Table 2. Quadratic discriminant analysis of turfgrass colorant cover, quality, and hue angle on Patriot and Celebration bermudagrass within the Group 1 colorants tested at the Lake Wheeler Field Laboratory in Raleigh, NC.

	Actual					
Predicted	Bermuda	Blue	Dye	Lawnger	Regreen	Wintergreen
Bermuda	25 (19.5)†	14 (10.9)	35 (27.3)	26 (20.3)	14 (10.9)	14 (10.9)
Blue	8 (6.3)	54 (42.2)	55 (43.0)	2 (1.6)	6 (4.7)	3 (2.4)
Dye	13 (10.2)	32 (25.0)	55 (43.0)	9 (7.0)	3 (2.3)	16 (12.5)
Lawnger	9 (7.0)	1 (0.8)	6 (4.7)	83 (64.8)	18 (14.1)	11 (8.6)
Regreen	17 (13.3)	11 (8.6)	26 (20.3)	32 (25.0)	22 (17.2)	20 (15.6)
Wintergreen	11 (8.6)	11 (8.6)	40 (31.3)	34 (26.6)	13 (10.2)	19 (14.8)
	Error count estimates for treatment					
Rate	0.8047	0.5781	0.5703	0.3516	0.8281	0.8516

† Values preceding parentheses represent the number of times a treatment was classified as another treatment while values within parentheses represent the percent of the total.

Table 3. Quadratic discriminant analysis of turfgrass colorant cover, quality, and hue angle on Patriot and Celebration bermudagrass within the Group 2 colorants tested at the Lake Wheeler Field Laboratory in Raleigh, NC.

	Actual												
Predicted	End	Envir	Ever	Graph	Lesco	Line	Orig	SWG	Solar	Spmax	Titan	UDP	UDS
End	10 (7.8)†	6 (4.7)	0 (0.0)	8 (6.3)	26 (20.3)	0 (0.0)	2 (1.6)	16 (12.5)	4 (3.1)	16 (12.5)	6 (4.7)	34 (26.6)	0 (0.0)
Envir	22 (17.2)	31 (24.2)	1 (0.8)	10 (7.8)	15 (11.7)	0 (0.0)	2 (1.6)	9 (7.0)	11 (5.6)	8 (6.3)	1 (0.8)	17 (13.3)	1 (0.8)
Ever	9 (7.0)	13 (10.2)	7 (5.5)	5 (3.9)	13 (10.2)	8 (6.3)	5 (3.9)	12 (9.4)	10 (7.8)	24 (18.8)	2 (1.6)	20 (15.6)	0 (0.0)
Graph	19 (14.8)	18 (14.1)	1 (0.8)	19 (14.8)	5 (3.9)	0 (0.0)	2 (1.6)	2 (1.6)	28 (21.9)	9 (7.0)	0 (0.0)	21 (16.4)	4 (3.1)
Lesco	17 (13.3)	11 (8.6)	2 (1.6)	2 (1.6)	31 (24.2)	0 (0.0)	4 (3.1)	13 (10.2)	12 (9.4)	16 (12.5)	4 (3.1)	16 (12.5)	0 (0.0)
Line	4 (3.1)	14 (10.9)	14 (10.9)	5 (3.9)	10 (7.8)	1 (0.8)	9 (7.0)	8 (6.3)	9 (7.0)	29 (22.7)	1 (0.8)	23 (18.0)	1 (0.8)
Orig.	11 (8.6)	13 (10.2)	5 (3.9)	15 (11.7)	16 (12.5)	0 (0.0)	2 (1.6)	2 (1.6)	29 (22.7)	10 (7.8)	0 (0.0)	18 (14.1)	7 (5.5)
SWG	10 (7.8)	10 (7.8)	1 (0.8)	2 (1.6)	20 (15.6)	0 (0.0)	3 (2.3)	21 (16.4)	3 (2.3)	24 (18.8)	1 (0.8)	32 (25.0)	1 (0.8)
Solar	17 (13.3)	12 (9.4)	5 (3.9)	24 (18.8)	17 (13.3)	0 (0.0)	8 (6.3)	2 (1.6)	33 (25.8)	2 (1.6)	3 (2.3)	2 (1.6)	3 (2.3)
Spmax	4 (3.1)	16 (12.5)	3 (2.3)	1 (0.8)	14 (10.9)	6 (4.7)	2 (1.6)	14 (10.9)	3 (2.3)	47 (36.7)	1 (0.8)	17 (13.3)	0 (0.0)
Titan	15 (11.7)	20 (15.6)	11 (8.6)	8 (6.3)	16 (12.5)	0 (0.0)	10 (7.8)	9 (7.0)	12 (9.4)	11 (8.6)	2 (1.6)	14 (10.9)	0 (0.0)
UDP	14 (10.9)	3 (2.3)	1 (0.8)	5 (3.9)	17 (13.3)	2 (1.6)	5 (3.9)	12 (9.4)	5 (3.9)	15 (11.7)	4 (3.1)	43 (33.6)	2 (1.6)
UDS	17 (13.3)	6 (4.7)	7 (5.5)	12 (9.4)	17 (13.3)	0 (0.0)	8 (6.3)	6 (4.7)	13 (10.2)	12 (9.4)	4 (3.1)	26 (20.3)	0 (0.0)
	Error count estimates for treatment												
Rate	0.9219	0.7578	0.9453	0.8516	0.7578	0.9922	0.9844	0.8359	0.7422	0.6328	0.9844	0.6641	1.000

† Values preceding parentheses represent the number of times a treatment was classified as another treatment while values within parentheses represent the percent of the total.

Table 12. continued

‡ Product abbreviations: End., Endurant; Envir., Go Green; Ever., Evergreen; Graph., Graphics; Lesco, Lesco Green; Line., Lineman; Orig., Original; SWG, Southwest Green; Solar., Solarogen; Spmax, SprayMax; Titan, Titan Green Turf; UDP, Ultradwarf Plus; UDS, Ultradwarf Super.

Table 4. Quadratic discriminant analysis of turfgrass colorant cover, quality, and hue angle on Patriot and Celebration bermudagrass within the Group 3 colorants tested at the Lake Wheeler Field Laboratory in Raleigh, NC.

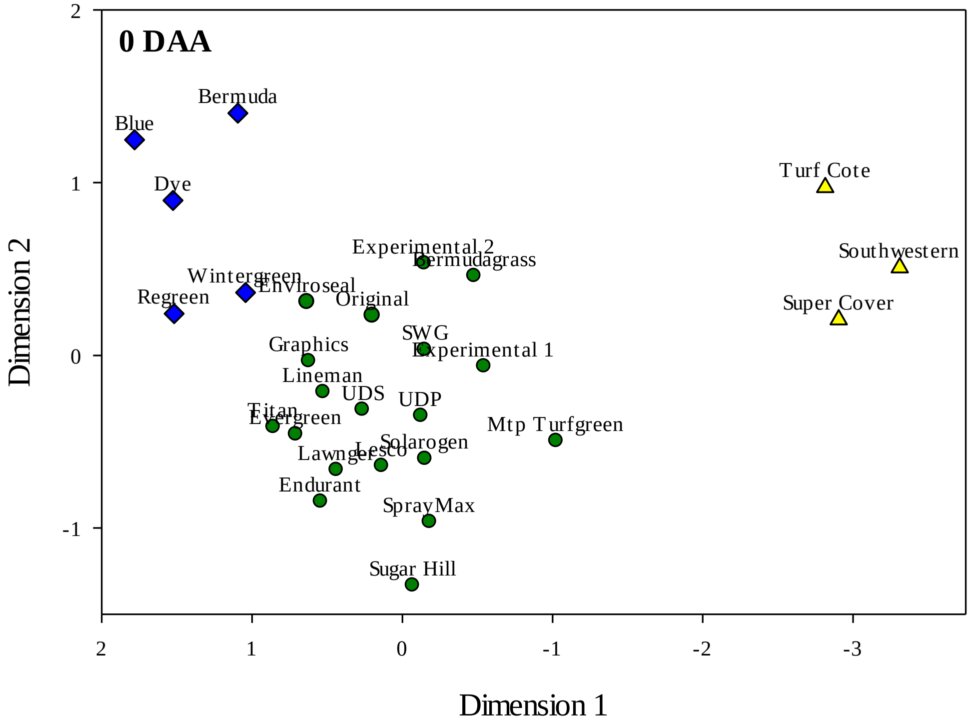
	Actual					
Predicted	Bermudagrass	Turf Cote	Super Cover	Mtp Turfgreen	Sugar Hill	Southwestern
Bermudagrass	74 (57.8)†	19 (14.8)	17 (13.3)	7 (5.5)	10 (7.8)	1 (0.8)
Turf Cote	8 (6.3)	100 (78.1)	7 (5.5)	10 (7.8)	2 (1.6)	1 (0.8)
Cover	19 (14.8)	66 (51.6)	12 (9.4)	13 (10.2)	14 (10.9)	4 (3.1)
Mtp Turfgreen	33 (25.8)	36 (28.1)	13 (10.2)	17 (13.3)	21 (16.4)	8 (6.3)
Sugar Hill	15 (11.7)	54 (42.2)	11 (8.6)	14 (10.9)	31 (24.2)	3 (2.3)
Southwestern	10 (7.8)	75 (58.6)	16 (12.5)	11 (8.6)	14 (10.9)	2 (1.56)
	Error count estimates for treatment					
Rate	0.4219	0.2188	0.9063	0.8672	0.7578	0.9844

† Values preceding parentheses represent the number of times a treatment was classified as another treatment while values within parentheses represent the percent of the total.

Appendix B

Additional Multidimensional Scaling Scatterplots

Figure 1. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Miniverde bermudagrass at 75 mL m^{-2} in November, 2011. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 0, 59, and 111 days after application.


0 DAA
Bermuda
Blue
Dye
Wintergreen
Enviroseal
Regreen
Experimental 2
Bermudagrass
Original
SWG
Experimental 1
Graphics
Lineman
UDS
UDP
Titan
Evergreen
Mtp Turfgreen
Solarogen
Lesco
Lawngier
Endurant
SprayMax
Sugar Hill
Turf Cote
Southwestern
Super Cover
Dimension 2
Dimension 1
2
1
0
-1
-2
-3

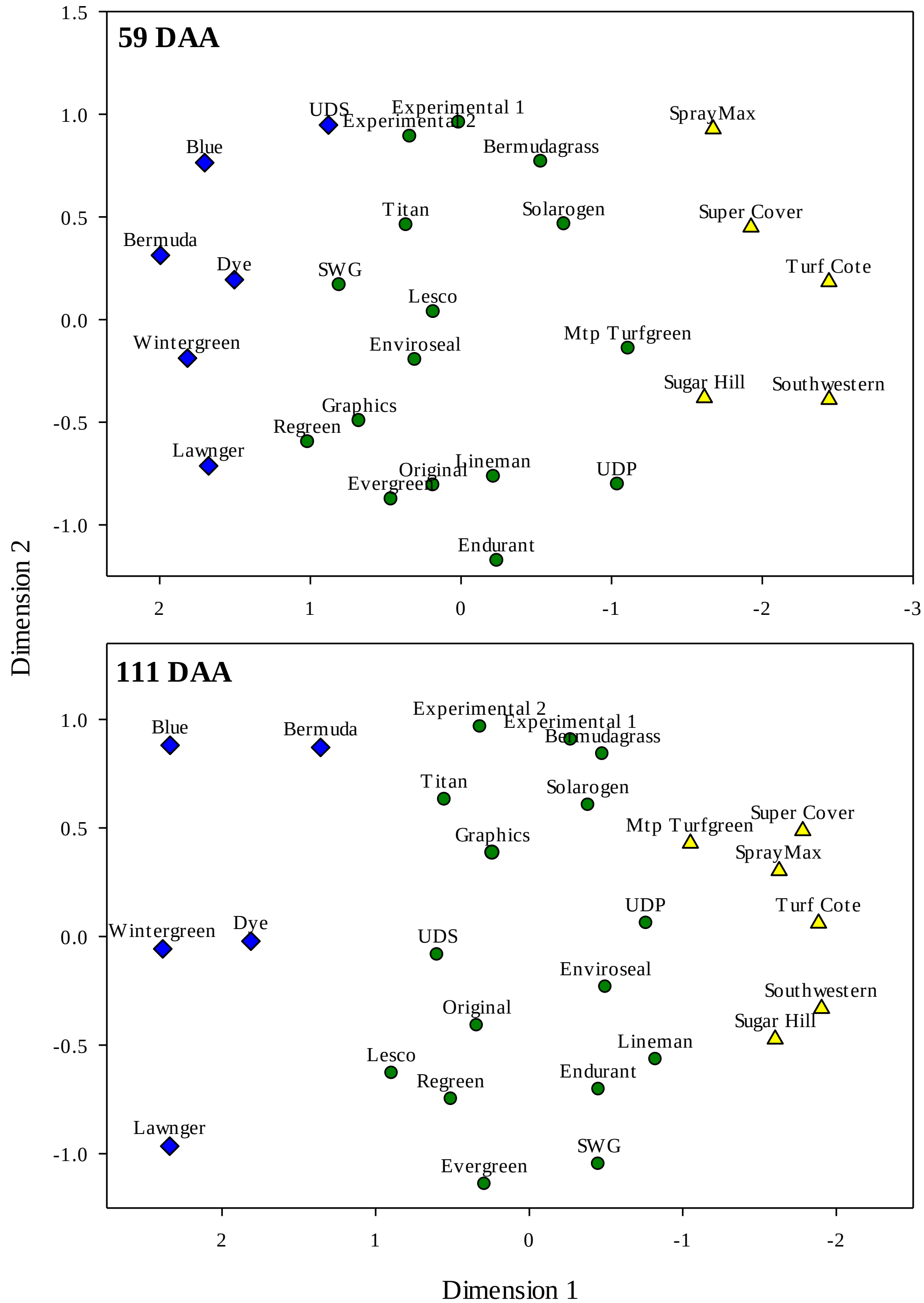
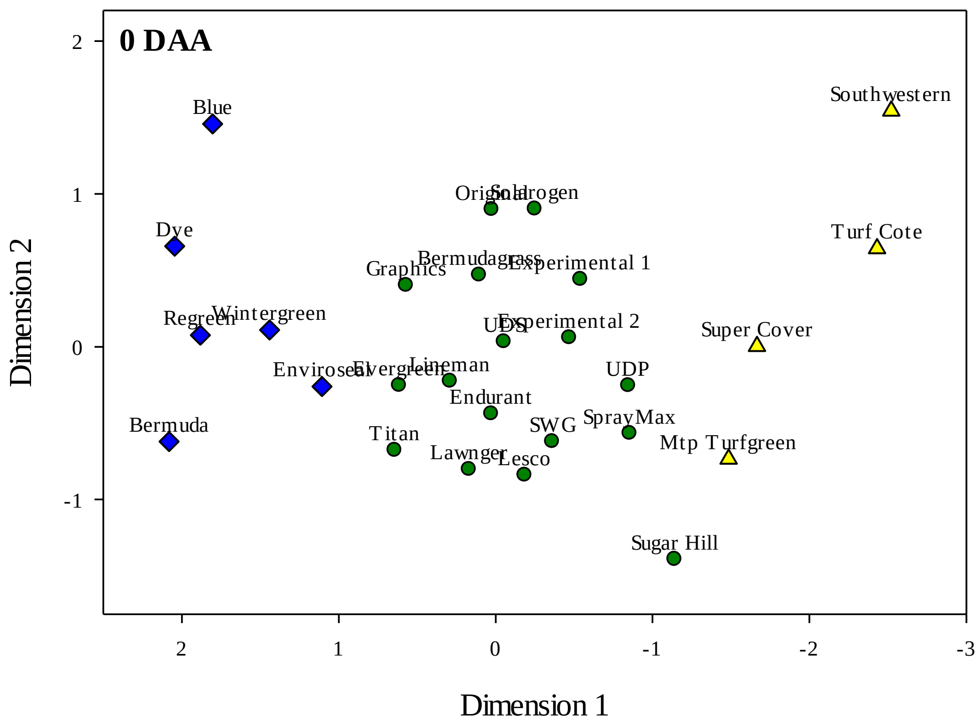

59 DAA
UDS
Experimental 1
Experimental 2
SprayMax
Blue
Bermudagrass
Titan
Solarogen
Super Cover
Bermuda
Dye
SWG
Turf Cote
Lesco
Mtp Turfgreen
Wintergreen
Enviroseal
Sugar Hill
Southwestern
Graphics
Regreen
Lawnger
Original
Lineman
UDP
Evergreen
Endurant
111 DAA
Experimental 2
Experimental 1
Blue
Bermuda
Bermudagrass
Titan
Solarogen
Super Cover
Mtp Turfgreen
Graphics
SprayMax
UDP
Turf Cote
Wintergreen
Dye
UDS
Enviroseal
Southwestern
Original
Sugar Hill
Lineman
Lesco
Endurant
Regreen
Lawnger
SWG
Evergreen
Dimension 2
Dimension 1

Figure 2. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Miniverde bermudagrass at 112 mL m^{-2} in November, 2011. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 0, 59, and 111 days after application.



0 DAA
Southwestern
Blue
Original
Solarogen
Turf Cote
Dye
Bermudagrass
Experimental 1
Graphics
Experimental 2
UDA
Super Cover
Regreen
Wintergreen
Envirosea
Evergreen
Lineman
UDP
Endurant
SprayMax
Bermuda
SWG
Mtp Turfgreen
Titan
Lawnger
Lesco
Sugar Hill
Dimension 1
Dimension 2
2
1
0
-1
-2
-3

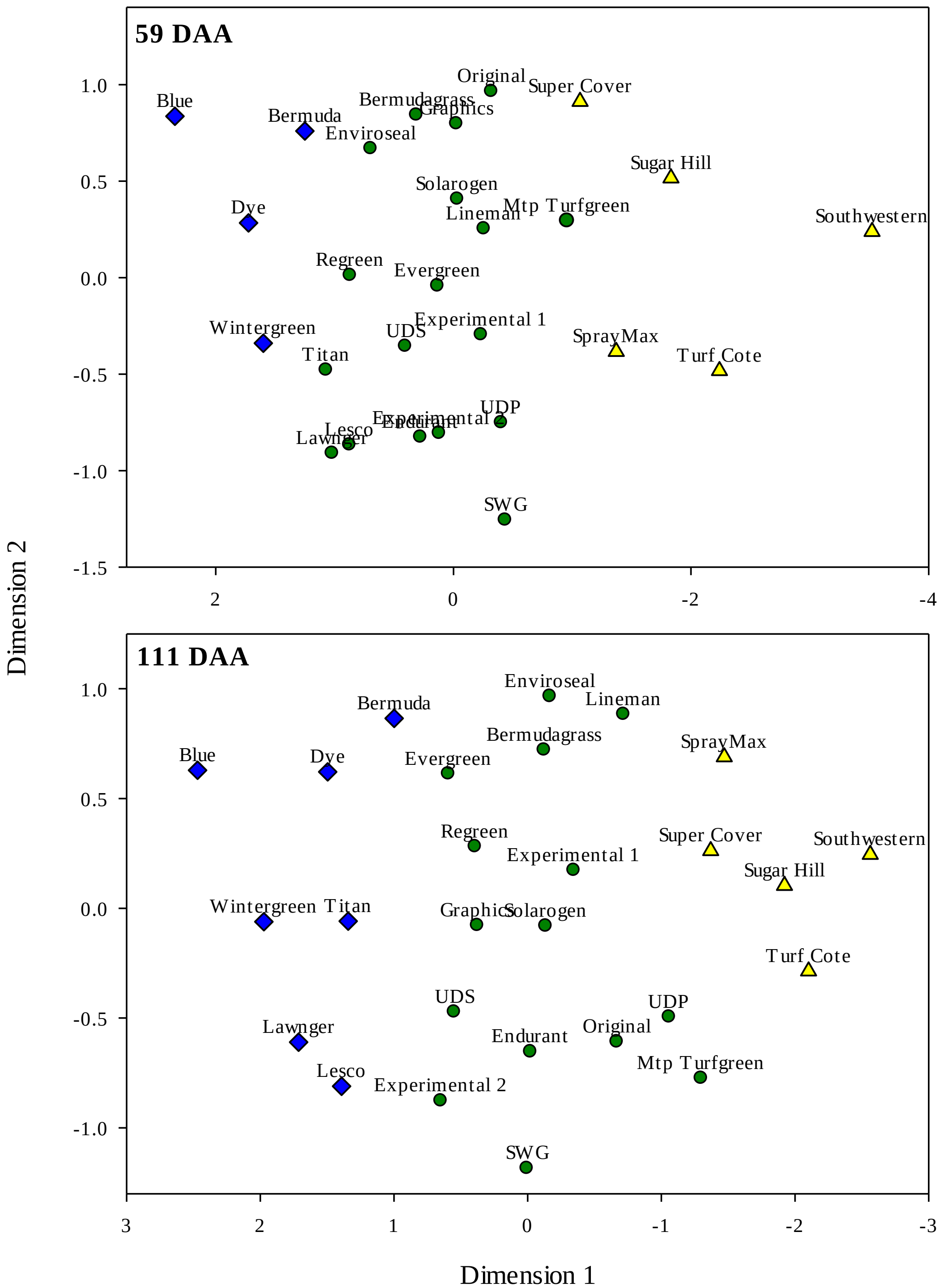
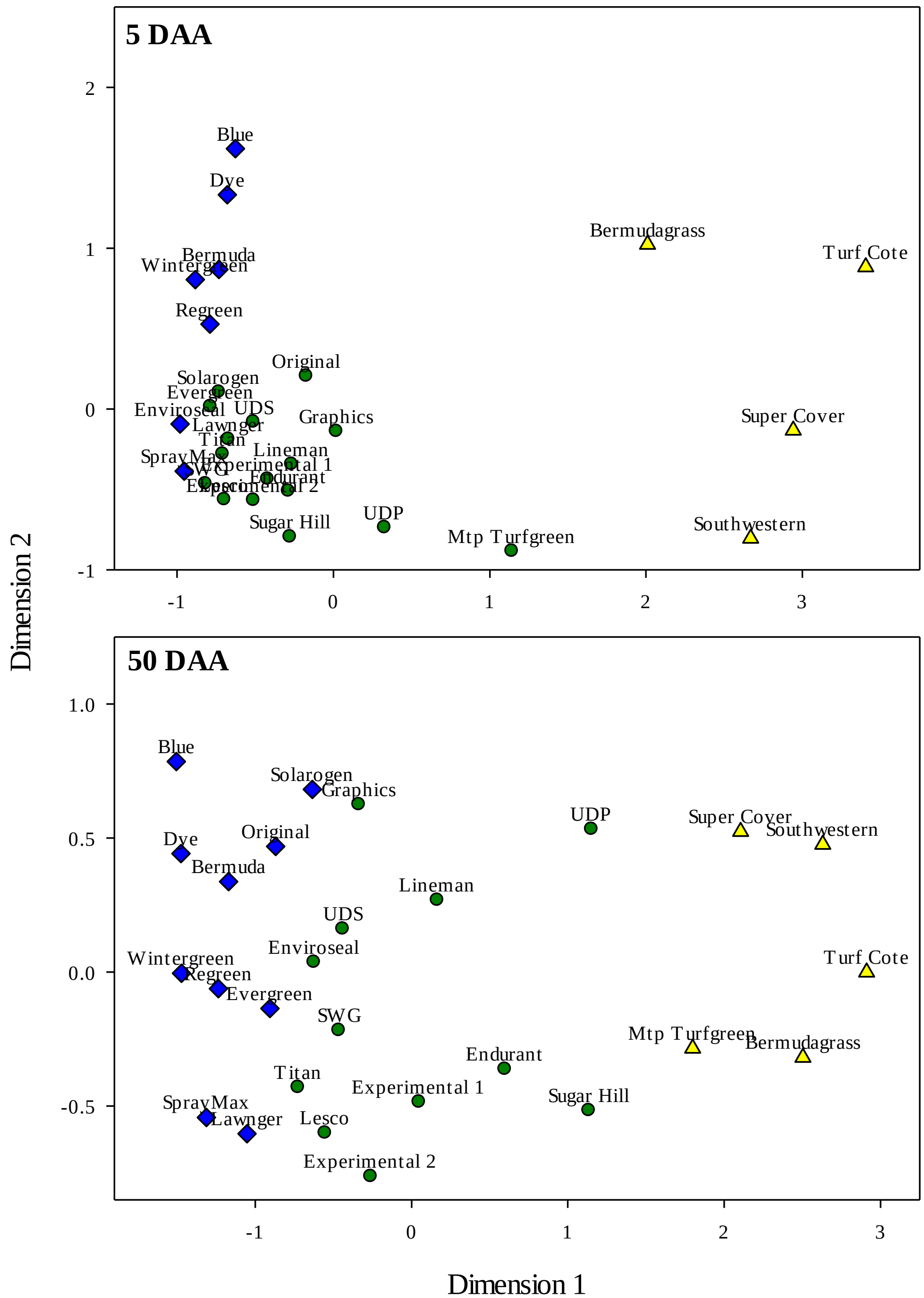

59 DAA
Blue
Bermuda
Enviroseal
Bermudagrass
Graphics
Original
Super Cover
Sugar Hill
Solarogen
Dye
Lineman
Mtp Turfgreen
Southwestern
Regreen
Evergreen
Wintergreen
UDS
Experimental 1
SprayMax
Turf Cote
Titan
UDP
Experimental 2
Endurant
Lesco
Lawnger
SWG
111 DAA
Enviroseal
Lineman
Bermuda
Bermudagrass
SprayMax
Blue
Dye
Evergreen
Regreen
Super Cover
Southwestern
Experimental 1
Sugar Hill
Wintergreen
Titan
Graphics
Solarogen
Turf Cote
UDS
UDP
Lawnger
Endurant
Original
Lesco
Mtp Turfgreen
Experimental 2
SWG
Dimension 2
Dimension 1

Figure 3. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Miniverde bermudagrass at 75 mL m^{-2} in November, 2012. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 5, 50, 95 and 138 days after application.


5 DAA
50 DAA
Dimension 2
Dimension 1
Blue
Dye
Bermuda
Wintergreen
Regreen
Original
Solarogen
Evergreen
Enviroseal
UDS
Lawnger
Graphics
Titan
Lineman
SprayMax
SWG
Experimental 1
Endurant
Experimental 2
Lesco
Sugar Hill
UDP
Mtp Turfgreen
Bermudagrass
Turf Cote
Super Cover
Southwestern

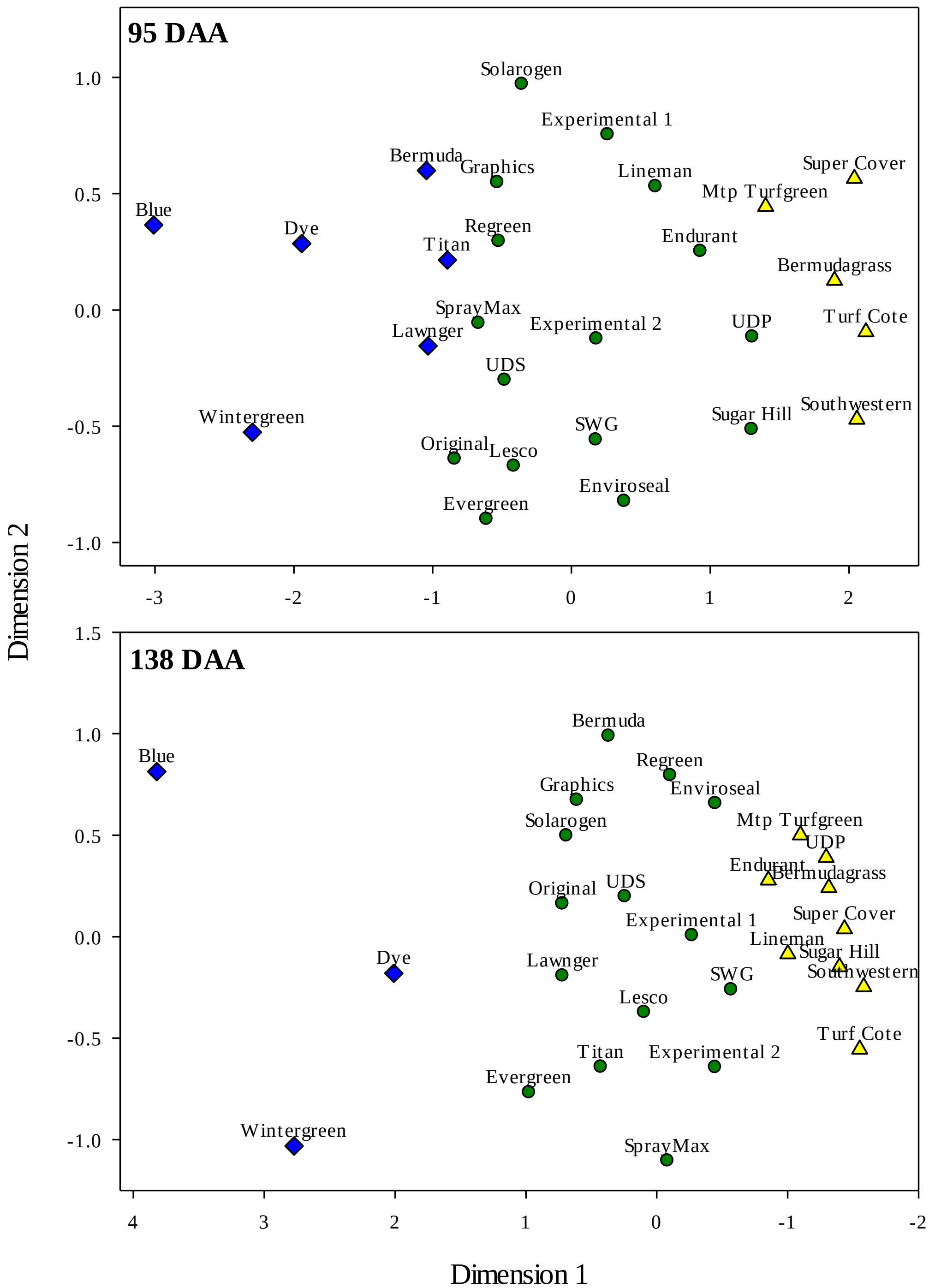
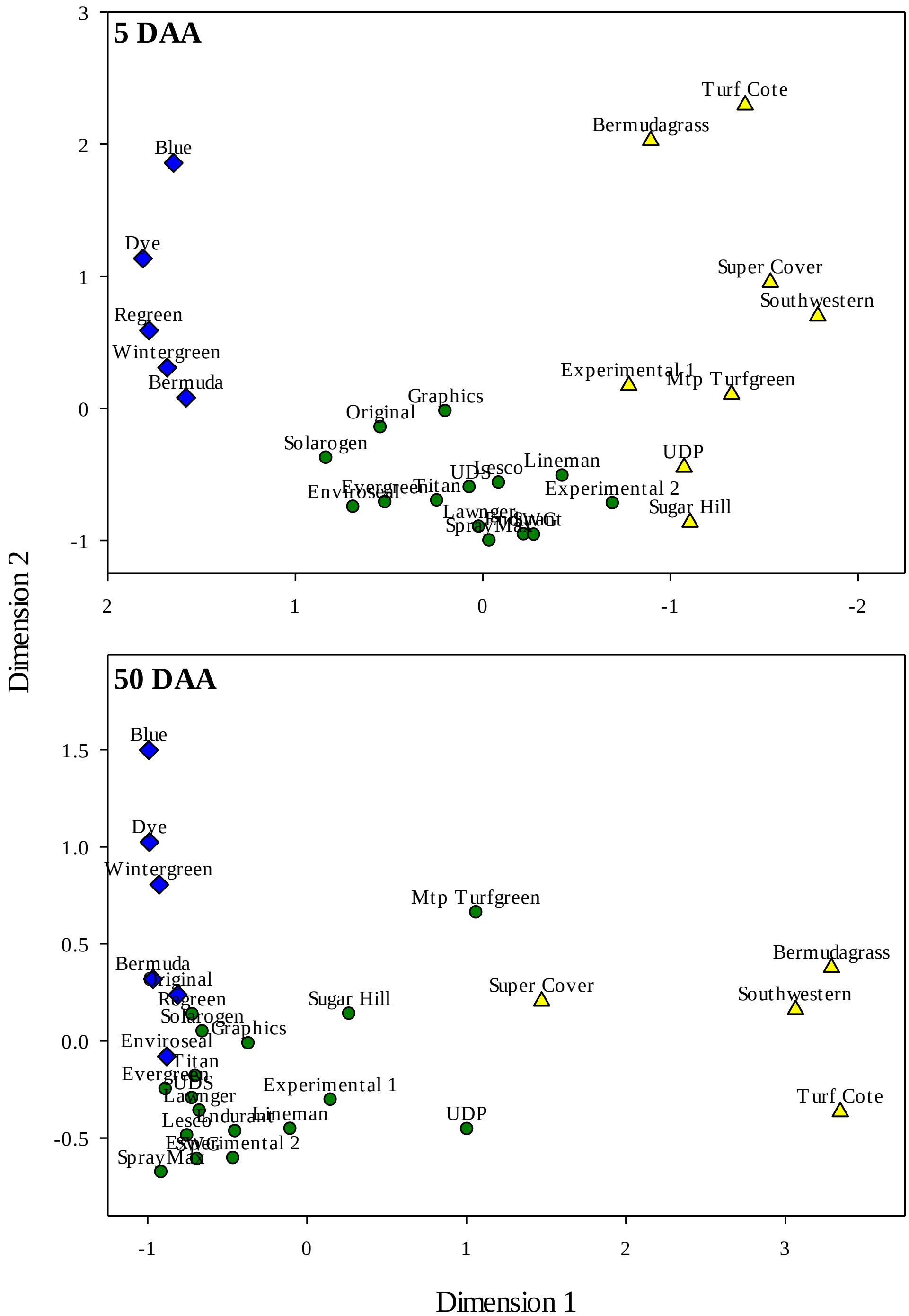

95 DAA
Solarogen
Experimental 1
Bermuda
Graphics
Lineman
Super Cover
Mtp Turfgreen
Blue
Dye
Regreen
Titan
Endurant
Bermudagrass
SprayMax
Lawnger
Experimental 2
UDP
Turf Cote
UDS
Wintergreen
SWG
Sugar Hill
Southwestern
Original
Lesco
Enviroseal
Evergreen
138 DAA
Bermuda
Blue
Regreen
Graphics
Enviroseal
Solarogen
Mtp Turfgreen
UDP
Endurant
Bermudagrass
Original
UDS
Experimental 1
Super Cover
Lineman
Sugar Hill
Dye
Lawnger
SWG
Southwestern
Lesco
Turf Cote
Titan
Experimental 2
Evergreen
Wintergreen
SprayMax
Dimension 2
Dimension 1

Figure 4. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Miniverde bermudagrass at 112 mL m^{-2} in November, 2012. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 5, 50, 95 and 138 days after application.



5 DAA
Turf Cote
Bermudagrass
Blue
Dye
Super Cover
Southwestern
Regreen
Wintergreen
Bermuda
Experimental 1
Mtp Turfgreen
Graphics
Original
Solarogen
UDP
Lineman
Lesco
UDS
Experimental 2
Enviroseal
Evergreen
Titan
Sugar Hill
Lawnger
SprayMax
SWG
50 DAA
Blue
Dye
Wintergreen
Mtp Turfgreen
Bermudagrass
Bermuda
Original
Regreen
Super Cover
Southwestern
Sugar Hill
Solarogen
Graphics
Enviroseal
Titan
Evergreen
UDS
Experimental 1
Lawnger
Turf Cote
Lineman
UDP
Lesco
Endurant
Experimental 2
SWG
SprayMax
Dimension 2
Dimension 1

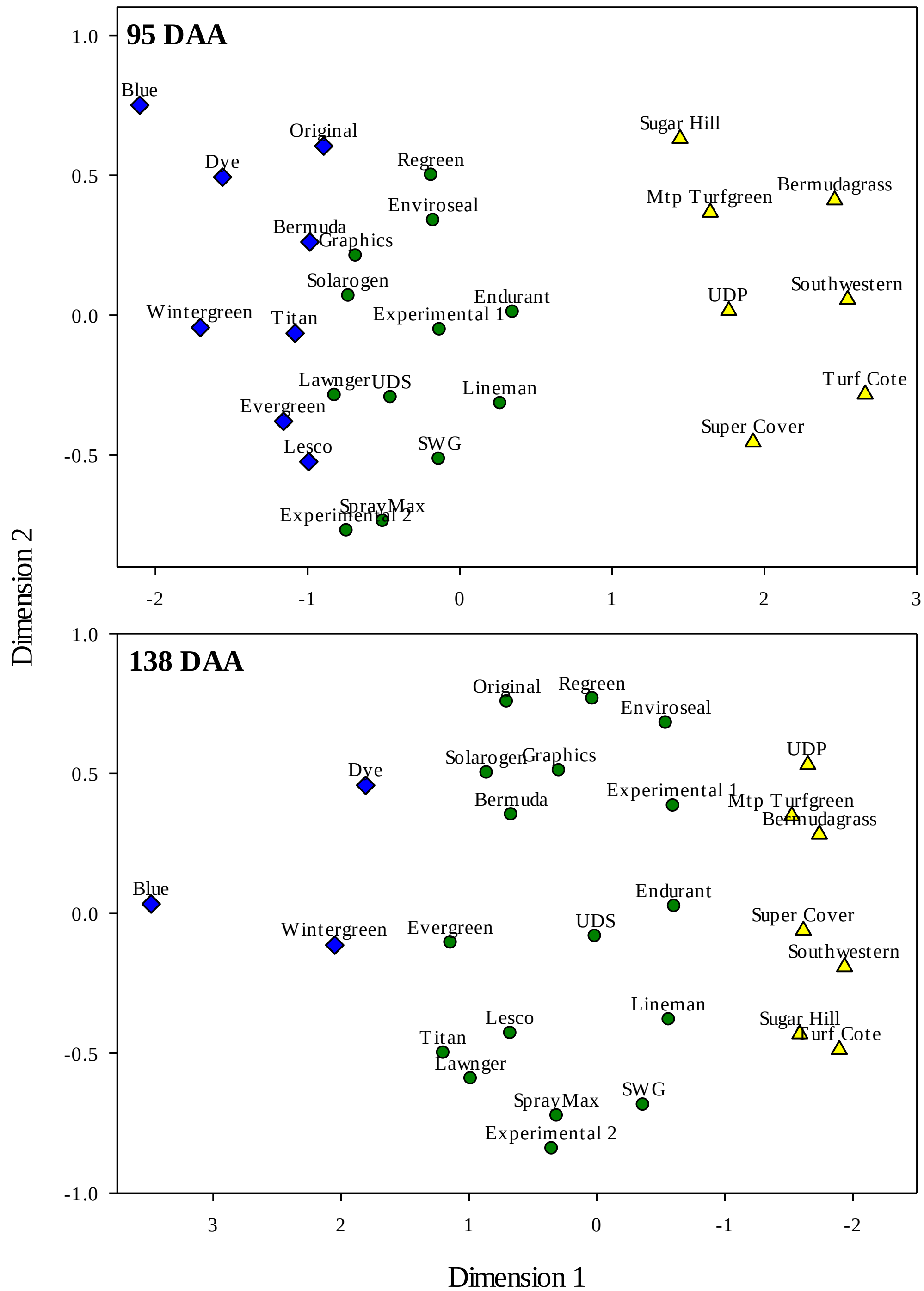
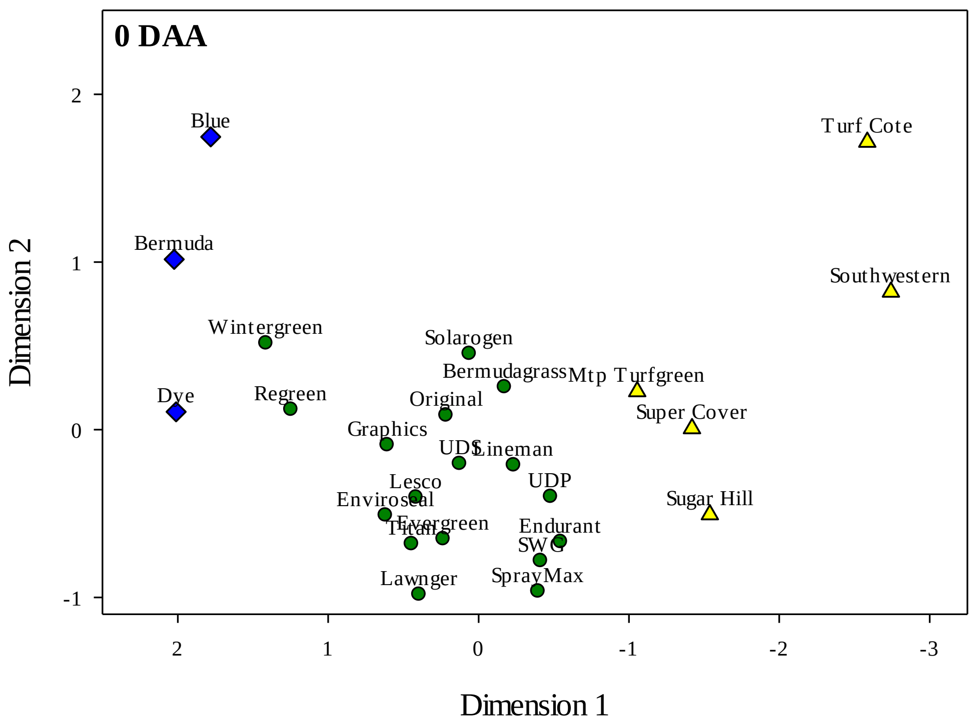

95 DAA
Blue
Original
Dye
Regreen
Sugar Hill
Bermudagrass
Mtp Turfgreen
Enviroseal
Bermuda
Graphics
Solarogen
Endurant
UDP
Southwestern
Wintergreen
Titan
Experimental 1
Lawnger
UDS
Lineman
Turf Cote
Evergreen
Super Cover
Lesco
SWG
SprayMax
Experimental 2
138 DAA
Original
Regreen
Enviroseal
Solarogen
Graphics
UDP
Dye
Experimental 1
Bermuda
Mtp Turfgreen
Bermudagrass
Blue
Endurant
Super Cover
Wintergreen
Evergreen
UDS
Southwestern
Lineman
Sugar Hill
Lesco
Turf Cote
Titan
Lawnger
SWG
SprayMax
Experimental 2
Dimension 2
Dimension 1
1.0
0.5
0.0
-0.5
-1.0
-2
-1
0
1
2
3

Figure 5. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Patriot bermudagrass at 75 mL m^{-2} in November, 2011. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 0, 43, and 99 days after application.


0 DAA
Blue
Bermuda
Dye
Wintergreen
Regreen
Solarogen
Bermudagrass
Original
Graphics
UDS
Lineman
Lesco
Envirosteal
Evergreen
Titan
Lawnger
UDP
Endurant
SWG
SprayMax
Mtp Turfgreen
Super Cover
Sugar Hill
Turf Cote
Southwestern
Dimension 1
Dimension 2
2
1
0
-1
-2
-3

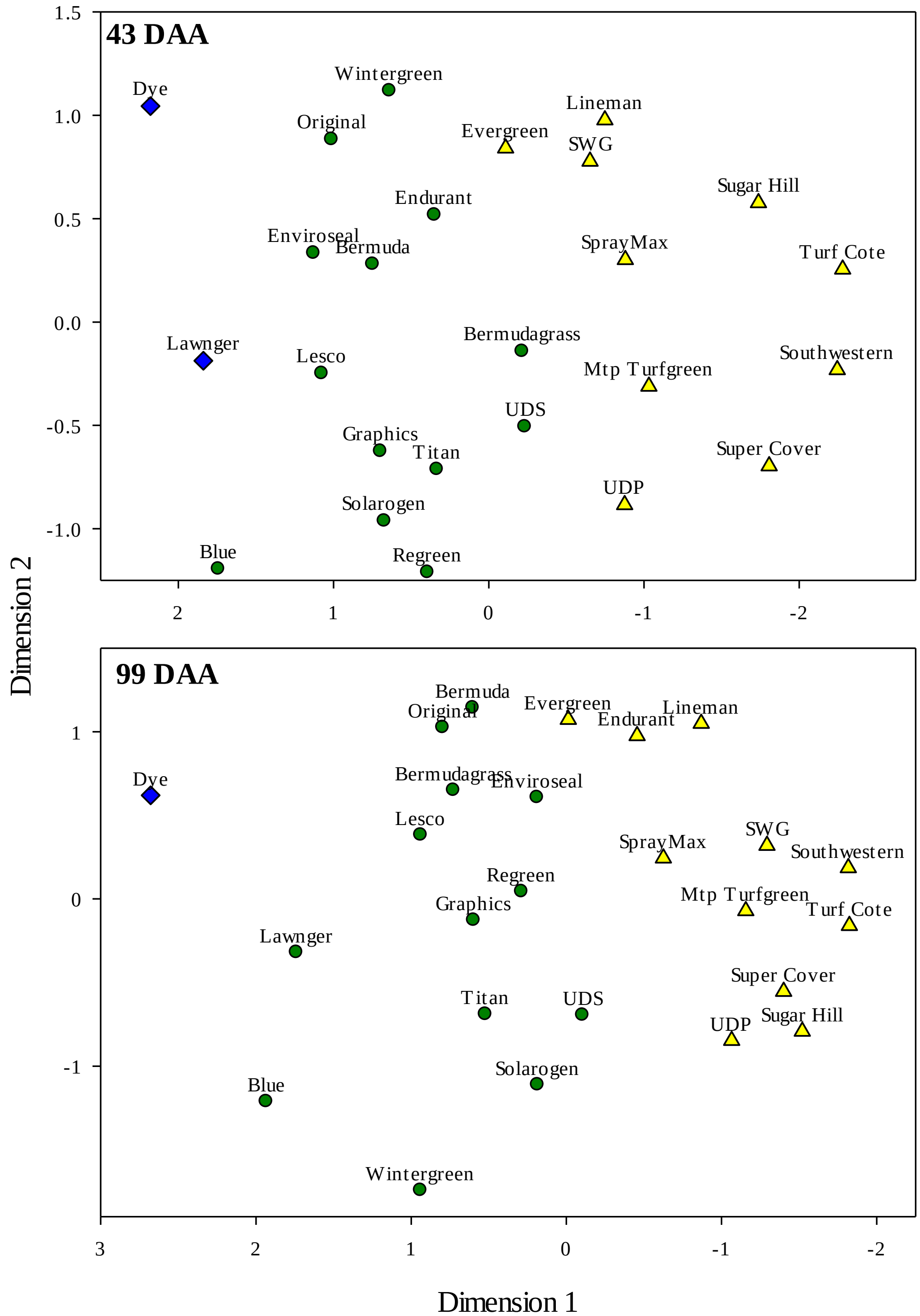
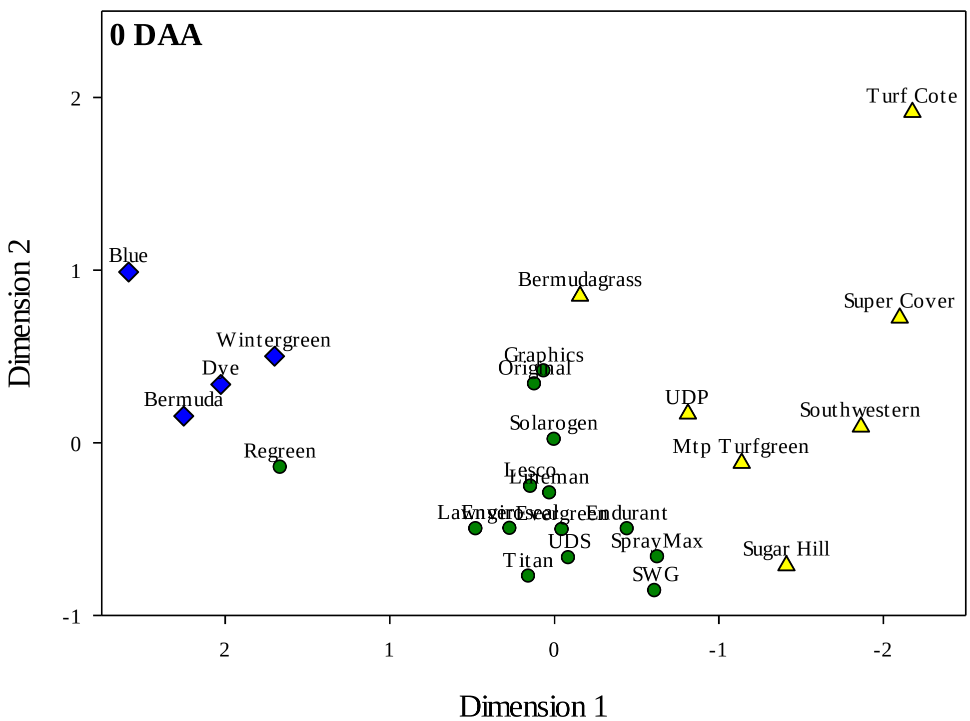

43 DAA
Dye
Wintergreen
Original
Evergreen
Lineman
SWG
Sugar Hill
Endurant
Enviroseal
Bermuda
SprayMax
Turf Cote
Lawnger
Lesco
Bermudagrass
Mtp Turfgreen
Southwestern
UDS
Graphics
Titan
Super Cover
UDP
Solarogen
Blue
Regreen
99 DAA
Bermuda
Original
Evergreen
Endurant
Lineman
Dye
Bermudagrass
Enviroseal
Lesco
SprayMax
SWG
Southwestern
Regreen
Graphics
Mtp Turfgreen
Turf Cote
Lawnger
Super Cover
Titan
UDS
Sugar Hill
UDP
Solarogen
Blue
Wintergreen
Dimension 2
Dimension 1
1.5
1.0
0.5
0.0
-0.5
-1.0
2
1
0
-1
-2
3

Figure 6. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Patriot bermudagrass at 112 mL m^{-2} in November, 2011. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 0, 43, and 99 days after application.


0 DAA
Dimension 2
Dimension 1
2
1
0
-1
-2
Turf Cote
Blue
Bermudagrass
Super Cover
Wintergreen
Graphics
Original
Dye
UDP
Bermuda
Southwestern
Solarogen
Regreen
Mtp Turfgreen
Lesco
Lifeman
Enviro Seal
Evergreen
Endurant
UDS
SprayMax
Sugar Hill
Titan
SWG

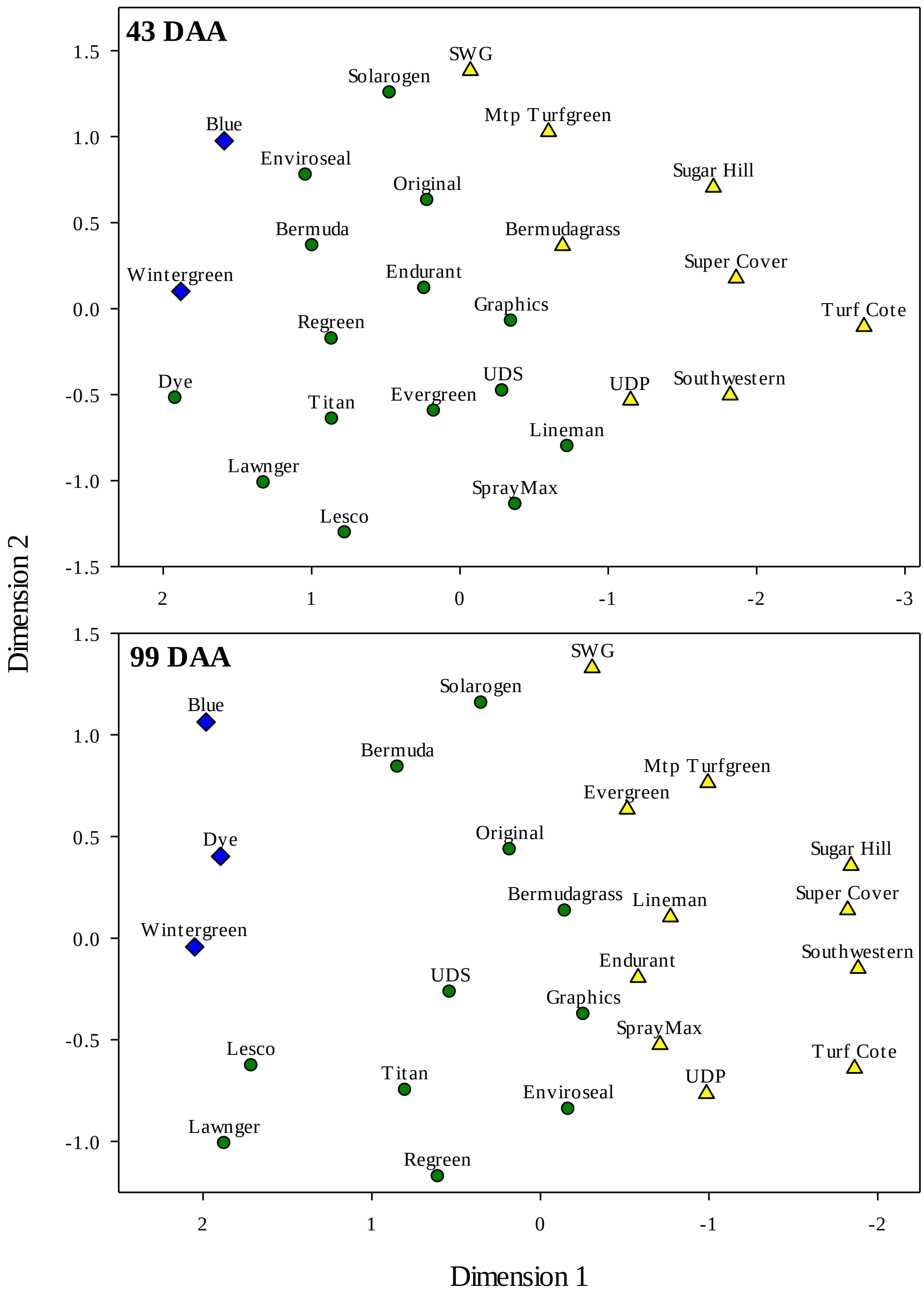
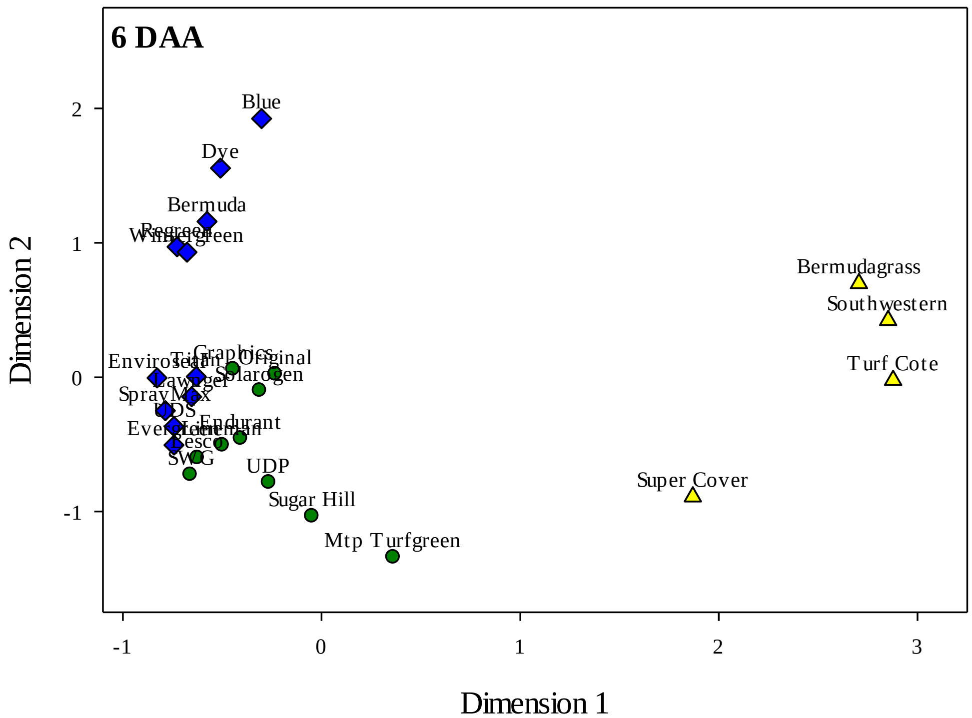
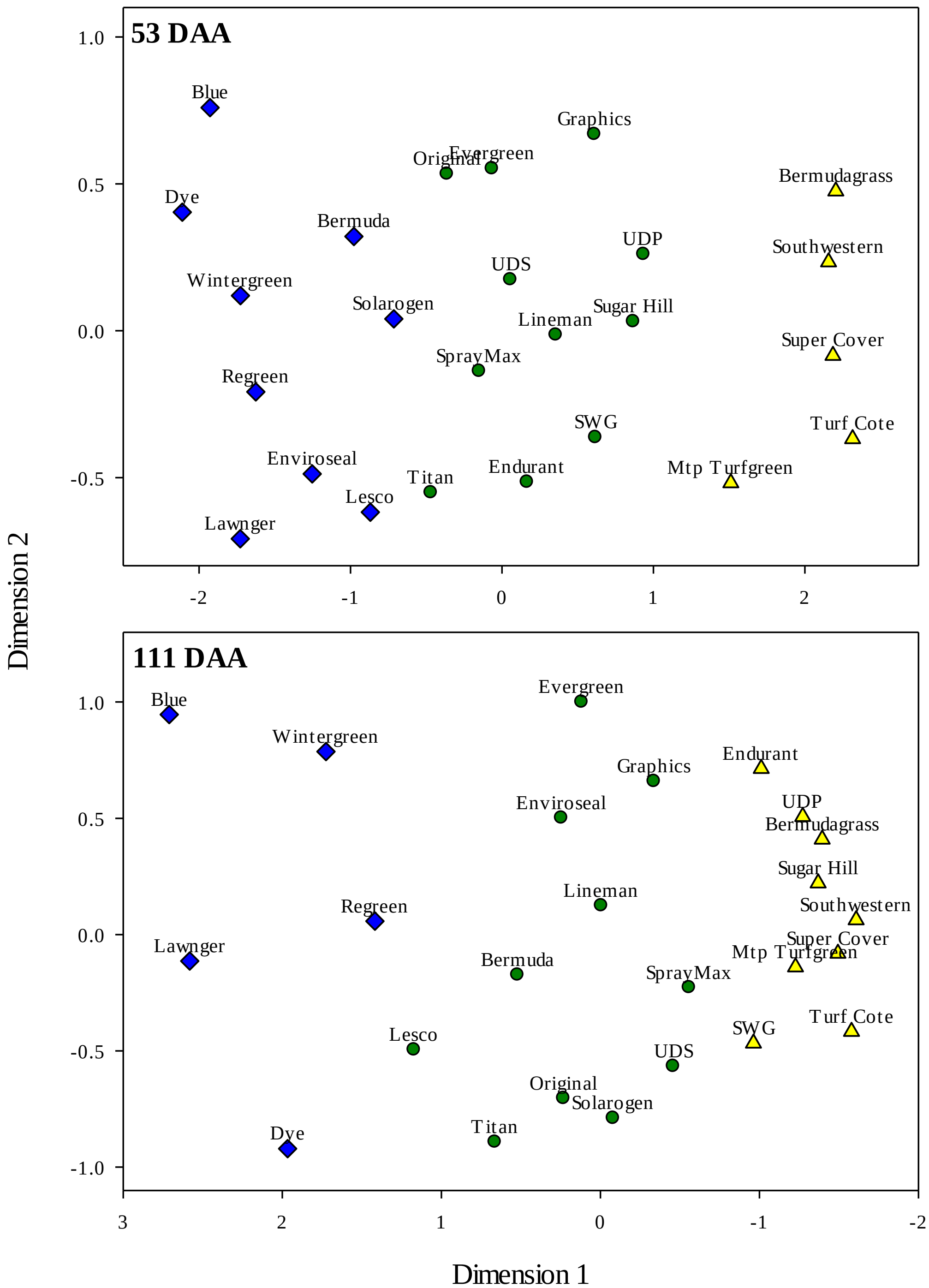

43 DAA
SWG
Solarogen
Mtp Turfgreen
Blue
Enviroseal
Sugar Hill
Original
Bermuda
Bermudagrass
Super Cover
Wintergreen
Endurant
Graphics
Turf Cote
Regreen
UDS
UDP
Southwestern
Dye
Titan
Evergreen
Lineman
Lawnger
SprayMax
Lesco
99 DAA
SWG
Solarogen
Blue
Bermuda
Mtp Turfgreen
Evergreen
Dye
Original
Sugar Hill
Bermudagrass
Lineman
Super Cover
Wintergreen
Endurant
Southwestern
UDS
Graphics
SprayMax
Lesco
Turf Cote
Titan
UDP
Enviroseal
Lawnger
Regreen
Dimension 2
Dimension 1

Figure 7. Multidimensional scaling (MDS) analysis scatterplots showing the similarities of turfgrass colorants applied to Celebration bermudagrass at 112 mL m^{-2} in November, 2012. MDS coordinates are clustered based on colorant coverage, quality, and hue. Abbreviations: 6, 53, and 111 days after application (DAA).


6 DAA
Blue
Dye
Bermuda
Wintergreen
Regreen
Bermudagrass
Southwestern
Turf Cote
Graphics
Original
Envirosafe
Solargreen
SprayMax
UDS
Endurant
Rescue
SWG
UDP
Super Cover
Sugar Hill
Mtp Turfgreen
Dimension 1
Dimension 2
2
1
0
-1
-1
0
1
2
3


53 DAA
Blue
Dye
Wintergreen
Regreen
Enviroseal
Lawnger
Lesco
Titan
Bermuda
Solarogen
Original
Evergreen
Graphics
UDS
UDP
Lineman
Sugar Hill
SprayMax
SWG
Endurant
Mtp Turfgreen
Bermudagrass
Southwestern
Super Cover
Turf Cote
111 DAA
Blue
Wintergreen
Lawnger
Regreen
Dye
Evergreen
Graphics
Endurant
Enviroseal
UDP
Bermudagrass
Sugar Hill
Lineman
Southwestern
Super Cover
Mtp Turfgreen
Bermuda
SprayMax
Lesco
SWG
Turf Cote
UDS
Original
Solarogen
Titan
Dimension 2
Dimension 1